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PILE DRIVING EQUIPMENT

DESIGN MANUAL 38.4
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MARCORPS TM 3895-15/1

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ABSTRACT

Selection criteria for use by qualified engineers are presented for commercially available pile driving equipment. Extensive guidelines on the proper use of such equipment and discussion of the effectiveness of various methods and procedures for pile installation are given. The contents also include on-site procedures for the foreman and inspector, vibratory hammer driving, impact driving, jetting, permafrost problems, energy calculations, pile damage avoidance, and underwater driving.

FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command with input from the Department of the Army, other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM Headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters (Code 04). As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

By order of the Secretaries of the Navy and Army.

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WEIGHT HANDLING EQUIPMENT AND
SERVICE CRAFT MANUAL

DM No.	Superseded Chapters in basic DM-38	Title
38.1	1	Cranes
38.2	2	Dredging Equipment
38.3	3	Yard Craft
38.4	4	Pile Driving Equipment
38.5	5	Towing Nonself-Propelled Floating Structures

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PILE DRIVING EQUIPMENT

Section 1. INTRODUCTION

1. SCOPE.

a. Discussion. Pile driving equipment, other than derrick-type rigs, usually is selected from available units and seldom is designed or manufactured for a particular project. Selection of proper driving equipment, particularly the hammer and accessories, is of the greatest importance, not only with regard to the efficiency and cost of the pile installation, but also with respect to the structural adequacy and efficacy of the pile itself. Experience indicates that an excessively heavy hammer can, and frequently does, damage a pile; a light hammer will not provide adequate penetration of a heavy pile even though required driving resistance is attained; and jetting can disturb an otherwise satisfactory bearing stratum. This manual presents criteria for the selection of appropriate, commercially available equipment that will be best suited to the job and presents guidelines for the proper use of such equipment.

b. Methods of Installing Piles. Pile driving conventionally refers to installing the pile by driving it into the ground under the action of a hammer. In its broadest sense, however, pile driving includes methods of installation where the action of the hammer is augmented by use of jets or where a hammer is not used at all (as in jacking, screwing, and pull down methods). Use of vibrators to achieve pile penetration also is a common technique. This manual presents a discussion of the effectiveness of various methods and procedures involved in installing piles.

c. Matters Not Covered. This manual does not consider the use or installation of so-called "bored piles." Such constructions are piers, rather than piles and often are referred to as "drilled piers." This manual also does not consider equipment required to install proprietary types of piling such as those with expanded bases, the so-called "root" piles, and certain types of caissons.

2. CANCELLATION. This manual on pile driving equipment, NAVFAC DM-38.4, Army TM 5-849-1 cancels and supersedes Chapter Four, NAVFAC DM-38, Weight Handling Equipment and Service Craft, of August 1975.

3. HEARING CONSERVATION. Impact sound pressure levels can be expected to exceed 140 dB when equipment of this type is used. Unprotected personnel exposed to these high impact sound pressure levels for extended periods of time may incur permanent hearing loss. Therefore, it is recommended that a qualified industrial hygienist be consulted to prescribe the appropriate degree of hearing protection necessary to preserve hearing.

4. RELATED CRITERIA. Certain criteria related to pile driving equipment appear elsewhere in this DM series and in Army Technical Manual TM 5-818-1. See the following DM sources:

Subject	Source
Cranes (including appurtenances)	DM-38.1
Pile Foundations	DM-7 Series
Piling	DM-25 Series

Section 2. SELECTION OF METHOD OF INSTALLATION

1. METHODS IN COMMON USE.

a. Impact Hammer. This is the most common method and consists of driving the pile into the ground by use of an impacting weight. The weight may be simply dropped on the end of the pile (drop hammer) or may be accelerated in its fall by steam pressure, air pressure, internal combustion (diesel), or by hydraulic pressure.

b. Vibratory Hammer. This method consists of weighting the pile (by applying the weight of the hammer) and then inducing a vibration into the pile, which vibration is transmitted from the pile into the ground. In some types of soil (principally granular, noncohesive soil) a critical frequency (or band of frequencies) will be found at which the pile penetrates into the ground under its own weight (supplemented by the weight of the hammer).

c. Jacking. The pile casing may be jacked into place and filled with concrete. Where a closed end casing is used, special equipment is limited to conventional screw or hydraulic jacks. Where an open end casing is used, a jet or miniature orange peel bucket is used for removing the core.

d. Screwing. Screw piles consist of a pile casing fitted with one or more turns of a helical screw having a larger diameter than the pile. Installation is made by screwing the casing into the ground to a predetermined level. Torque is provided by a capstan or similar device.

e. Preboring. Preboring consists of drilling, augering, or coring a hole in the ground and placing concrete in the hole. The hole may be cased or uncased. Installation is made by using conventional drilling equipment or by alternately driving and withdrawing a casing and removing the contained soil plug. Augers are available in sizes up to 6 feet in diameter and can drill up to 200 feet deep. As noted in Section 1, this type of construction more properly is a pier than a pile and will not be considered further herein.

2. SELECTION FACTORS.

a. Availability of Equipment. The Navy may rent pile driving equipment, or use Government-owned equipment. First consideration should be given to the use of Government-owned equipment. If suitable equipment is not available as Government-owned, then select rental equipment on the following basis.

b. Noise. The entire matter of allowable noise disturbance is subjective and should be carefully evaluated before seeking special methods to reduce its effect. Pile driving, basically, is a noisy operation. Often, proper explanation of needs and alternatives and/or judicious selection of hours of operation can eliminate confrontation over the problem. (See also paragraph 5ℓ, Section 3.) Where noise must be limited, jacking and screwing methods are likely to provide the least disturbance. Use of an impact hammer is likely to produce the highest sound pressure levels (in terms of decibels). Preboring and use of vibratory hammer may produce lower sound pressure levels, but may not be less disturbing than use of an impact hammer.

c. Vibration Problems. The vibration due to pile driving shall be considered concerning possible damage to adjacent construction. Damage due to vibration is a function of both amplitude and frequency (see Figure 1). Attempts to predict whether or not a significant problem will occur in any given case are highly problematic and beyond the scope of this text. If a problem occurs, however, a first solution could be to decrease the amplitude (lighter hammer, for example, or different type of hammer) or to change the frequency (double acting instead of single acting hammer, for example, or use of vibratory hammer). These recourses failing, it may be necessary to adopt a method of installation other than impact driving.

d. Obstructions. Where piles must penetrate ground containing numerous obstructions, use of jacked or screw piles generally is not attempted. However, open-end jacked piles can penetrate through obstructions by use of a chopping bit or a light charge of explosives to clear the obstruction. The usual procedure is to use a heavy pile, a heavy hammer and to try to force a way through. This procedure invites damage to the pile and must be used with caution and only when the pile section has been conservatively proportioned. Alternatively, a spud is used. This is a section of heavy pile which is driven through, or past, the obstruction, removed for reuse, and the pile inserted through the passage so cleared.

If the group size and spacing permit, it also is feasible to probe for a way through, or past the obstructions. Use of a vibratory hammer, in which the pile can be readily extracted and reinserted, several times if need be, may be a useful solution to this problem.

e. Limited Overhead Clearance. This construction situation may dictate the use of a specific hammer or the jacking of piles in multiple sections.

f. Type of Pile. The type of pile tends to influence the method of installation. For example, certain types of piles cannot readily be driven with a vibratory because of difficulties in coupling the hammer to the pile. Jacking may not be feasible with displacement type piles in firm ground.

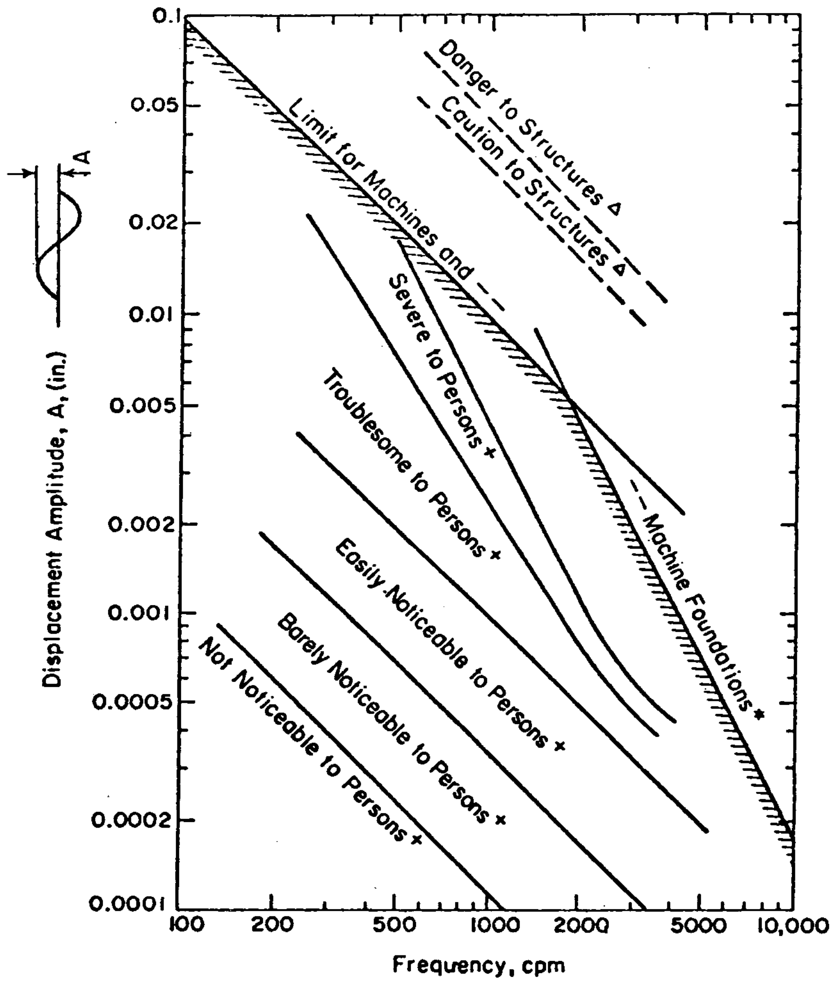
g. Other Factors. The requirements of the foundation design may dictate use of certain methods of installation. For example, the designer may desire the use of impact driving to compact the soil around the piles and hence increase the pile resistance under load. Normally, if this is a consideration, it should be stated by the designer in the project specifications so that the pile driving field crews will know what is expected.

Section 3. IMPACT DRIVING--SELECTION OF EQUIPMENT

1. SELECTING THE HAMMER.

a. Hammer Characteristics. See Table 1.

b. Minimum Energy. See Table 2.



+ From Reiher and Meister (1931) - (Steady State Vibrations)
* From Rausch (1943) - (Steady State Vibrations)
Δ From Crandell (1949) - (Due to Blasting)

FIGURE 1
Physical Effects of Various Combinations of Vibration Frequency and Amplitude

TABLE 1

Pile Hammers--Characteristics

Type	Description	Advantages	Disadvantages
Drop Hammer	Hammer is raised by rope running over top of a framework and extending back to a drum or geared shaft; blow is delivered by the fall of the hammer under the influence of gravity.	1. Allows greater variation in weight and speed of blows. 2. Low initial cost and practically indestructible. 3. Remote locations or where mechanical equipment is not obtainable.	1. Very low frequency of blows. 2. Reduction in efficiency due to drag of rope and drum. 3. Cannot be inverted and used as pile extractor. 4. Cannot be used in locations where headroom is limited. 5. Not readily adaptable for driving batter piles.
Single-acting hammers	Steam or air raises the movable mass of the hammer, which drops by gravity.	1. Efficient 2. Good performance 3. Simple in design and dependable in service. 4. Usable in all soil conditions, but particularly effective in penetrating heavy clays.	1. Relatively low frequency of blows, 50-60 per minute. 2. Cannot be used as an extractor.
Double-acting hammers	Steam or air raises the striking part and also imparts additional energy during downstroke.	1. High frequency of blows (90-150 per minute) keeps pile moving and speeds penetration. 2. Can be used in horizontal position. 3. Work best in sandy soil, but can be used in any soil. 4. Can be inverted and used as pile extractor. 5. Enclosed ram permits underwater driving.	1. Relatively high impact velocity results in pile head deformation of low compressive strength piles.
Differential-acting hammers	Variation of double-acting hammer. Valving arrangement is different.	1. Frequency of blows approaches that of double-acting hammer while the ram weight is the same as for single-acting hammers. 2. Can be used in horizontal position. 3. Work best in sandy soil, but can be used in any soil. 4. Can be inverted and used as pile extractor. 5. Enclosed ram permits underwater driving.	1. Relatively high impact velocity results in pile head deformation of low compressive strength piles.
Diesel hammers ...	Self-contained unit which uses ignition of fuel to impart additional energy during downstroke to drive pile downward and ram upward.	1. Independent of outside power sources (boiler, compressor, etc.) 2. Light weight and easily portable. 3. Low operating cost. 4. Maintenance and service are a minimum. 5. Ease of operation in cold weather. 6. Frequency of blows--50 to 105	1. Cannot be inverted and used as pile extractor. 2. In soft driving, may stall due to inadequate rebound.

TABLE 1 (Continued)

Type	Description	Advantages	Disadvantages
Vibratory hammer .	Vibrators attached to top of piling; pile is driven by weight and vibrator action.	1. Very fast driving under right conditions. 2. Rapid extraction possible. 3. Can be used for compaction of loose soil. 4. Less noisy than impact hammer.	1. Ineffective where point resistance is appreciable. 2. Not readily adaptable for driving batter piles. 3. Not applicable for use with all kinds of piles.
Petrol Drivers ...	Explosion of benzene or gasoline lifts ram and allows it to fall under its own weight; made only in Europe.	1. Light weight. 2. Independent of outside power sources.	1. Low frequency of blows. 2. Can only drive short, lightweight piles.

TABLE 2
Suggested Minimum Hammer Energy--Impact Hammers*

<u>Class I - Timber Piles</u>		
Capacity to 20 Tons	- 7500 Ft.-lb.	
Capacity over 20 Tons to 25 Tons	- 9000 Ft.-lb.	(Single-acting hammers)
	- 14000 Ft.-lb.	(Double-acting hammers)
Capacity over 25 Tons	- 12000 Ft.-lb.	(Single-acting hammers)
	- 15000 Ft.-lb.	(Double-acting hammers)
<u>Class II - Concrete and Steel Piles</u>		
Capacities to 60 Tons	- 15000 Ft.-lb.	
Capacities over 60 Tons	- 19000 Ft.-lb.	

*The values in this table are taken from the New York City Building Code of 1965. They are not universally applicable nor universally accepted. They are presented here for guidance.

c. Minimum Weight of Hammer. If the ratio of weight of pile to weight of the striking parts of the hammer is too high, the hammer cannot effectively overcome the inertia of the pile and the apparent values of penetration resistance will be misleading. At the present state of the art, the matter lacks definitive analysis. A rule of thumb in common use is that the weight of the pile should not exceed 3 times (some practitioners use a value of 2 times) the weight of the striking part of the hammer. Another rule of thumb is that, when driving precast concrete piles, the weight of the striking part of the hammer should be at least 30 times the weight of a one-foot length of the pile. The purpose of this latter rule is to avoid excessive, sustained driving which would tend to damage the pile.

d. Soil Characteristics. In modem practice, it is customary in the design phase for the designer to indicate minimum penetration (in terms of depth or tip elevation) required for piling. It is up to the pile driving superintendent to provide these penetrations, if feasible. Sometimes the resistance to penetration builds up before the desired tip elevation is attained, to the extent that the pile cannot be penetrated further without excessive risk of damage. (Figure 2 may be used as an aid in judging the probability of the event.) In such case, in cohesive soils, a high speed hammer often will provide greater penetration than will a slower hammer. In dense, granular soils, and, sometimes in stiff clays, hardpans, or shale, a slow, heavy hammer often will provide greater penetration than will a faster hammer. In all cases, one or more of the devices or appurtenances as hereinafter described and as listed in Table 3, will assist in increasing pile penetration.

e. Miscellaneous Hammers. Double, or differential, acting hammers can be fitted for horizontal driving or for driving underwater. Several manufacturers produce hammers specifically designed for underwater driving. A hammer specially designed to operate in depths of up to 800 feet is illustrated in Figure 3.

f. Data on Commercial Hammers. Tables 4 to 6. These tables give detailed data on several types of commercially available pile hammers. These tables are not intended to be complete, neither is the inclusion of a hammer in these tables to be construed as approval or recommendation of the equipment listed. The data is intended for handy reference and assistance in the selection of pile driving equipment. The concept of "or equivalent" shall apply to the procurement of any equipment not so listed.

2. SELECTING THE DRIVING RIG. Specially built pile driving rigs (on turntables, rollers, skids, or tracks) are in use, but the most common type of rig is a commercial crane adapted for pile driving (Figure 4) by equipping with boom adapters (several types are shown in Figure 5), leads, and appurtenances. Opinions as to the relative efficacy of the different types of special rigs (and their efficacy compared to that of the adapted commercial crane) vary widely. As a result, choice of the type of rig to be used, normally, is a matter of "what is available" and selection is limited to the type of leads and power equipment to suit the hammer selected, and accessories, as hereinafter described. Most land rigs and floating cranes can be adapted for use as floating pile drivers.

In selecting the driving rig, verify that there are an adequate number of weight-handling lines--one for the hammer, one for the pile, and, if hanging leads are to be used, one for the leads. (This would require a crane.)

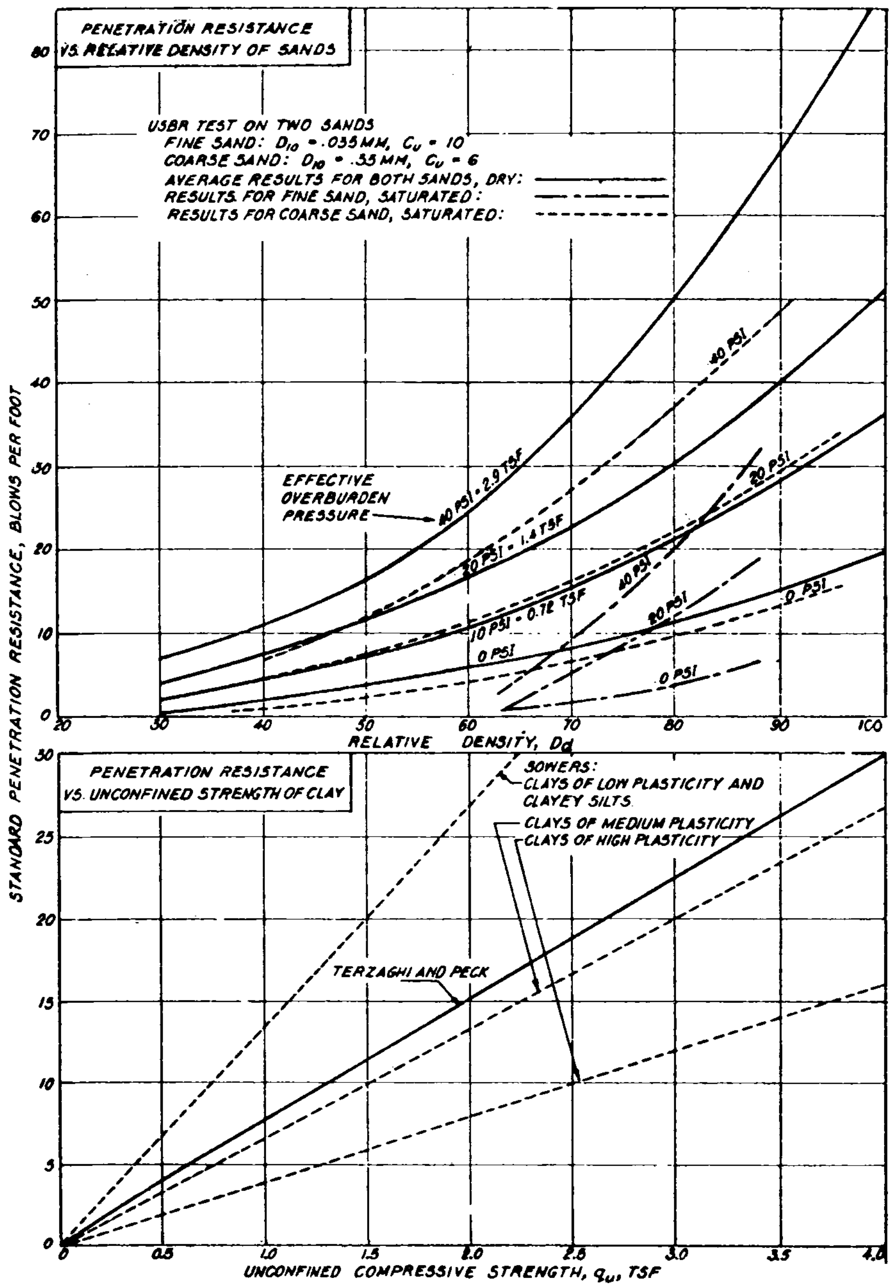


FIGURE 2
Correlations of Standard Penetration Resistance

TABLE 3
Supplementary Procedures and Appurtenances Used in Pile Driving

Method	Equipment and Procedure utilized	Applicability
Means of reducing driving resistance above bearing stratum:		
Temporary casing	Open end pipe casing driven and cleaned out. May be pulled later.	a. To drive through minor obstructions. b. To minimize displacement. c. Prevent caving or squeezing of holes. d. Permit concreting of pile prior to excavation to subgrade of foundation.
Precoring	By continuous flight auger or churn drill, a hole is formed into which the pile is lowered. Pile is then driven to bearing below the cored hole.	a. For driving through thick stratum of stiff to hard clay. b. To avoid displacement and heave of surrounding soil. c. To avoid injury to timber and thin shell pipes. d. To eliminate driving resistance in strata unsuitable for bearing.
Spudding	Heavy structural sections or closed end pipes are alternately raised and dropped to form a hole into which pile is lowered. Pile is then driven to bearing below the spudded hole.	a. For driving past individual obstruction. b. To drive through strata of fill with large boulders or rock fragments.
Jetting	Water, air or mixture of both forced through pipe at high pressures and velocity, jets are sometimes built into piles.	a. Used in practically all soils to reduce friction in strata unsuitable for bearing during driving of pile.
Means of increasing driving resistance in bearing stratum:		
Upside down piles	Tapered piles, specifically timber, driven with large butt downward.	a. For end bearing timber piles where it is necessary to minimize penetration into bearing stratum. b. To avoid driving through to incompressible but unsuitable bearing material.
Lagging	Short timber or steel sections connected by bolting or welding to timber or steel pipes.	a. To increase frictional resistance along sides of pile. b. Increase of end bearing resistance when mounted near tip.
Means of overcoming obstructions:		
Shoes and reinforced tips.	Metal reinforcing, such as bands and shoes for all types of piles.	a. To provide protection against damage of tip. b. To provide additional cutting power.
Explosives	Drill and blast ahead of pile tip.	a. To remove obstructions to open end piles under very severe conditions.
Pre-excavation	Hand or machine excavation.	a. Used for removal of obstruction close to ground surface.
Special equipment for advancing piles:		
Jacking	Hydraulic or mechanical screw jacks are used to advance pile. Pile is built up in short, convenient lengths.	a. Used instead of pile hammer where access is difficult. b. To eliminate vibrations.
Vibration	High amplitude vibrators.	a. Advantageous for driving in waterlogged sands and gravel. b. Advantageous for driving sheetpiling.
Follower	Temporary filler section between hammer and pile top, preferably of same material as pile.	a. To drive pile top to elevation below reach of hammer or below water.

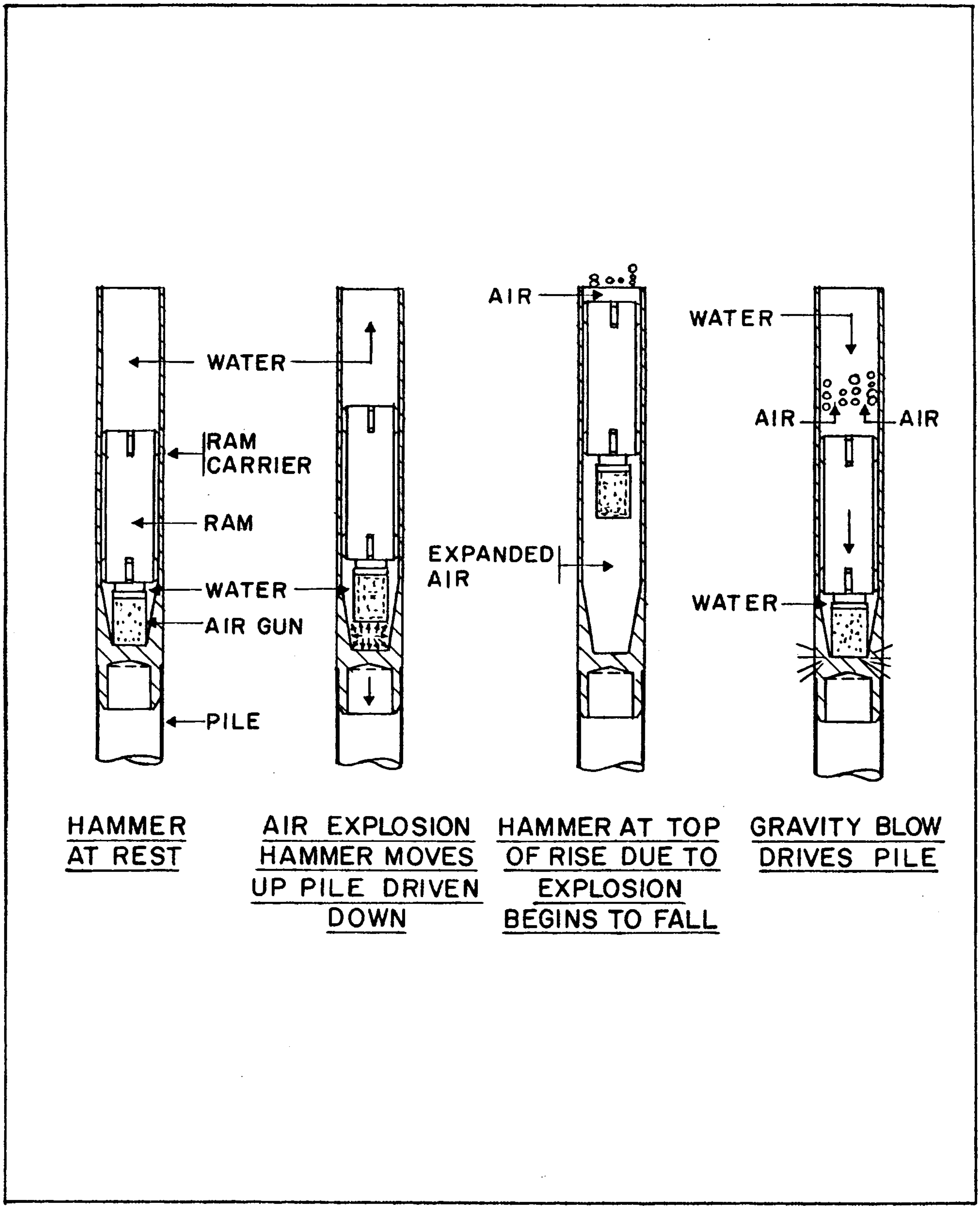


FIGURE 3
Underwater Hammer for Use in Deep Water

TABLE 4
Data on Impact Type Pile Hammers in Current Manufacture

Rated Energy (Ft.-Lb.)	Mfgr.	Model	Type	Speed (Blows/Min.)	Ram Weight (Lbs.)	Stroke (In.)	Air or Stream (PSI)	Net Weight (Lbs.)	Length (Ft.-In.)	Submersible
260,000	Kobe	K-150	Sgl. Act. Diesel	45-60	33,100	88	-	80,000	29-8	
159,000	Kobe	KB-80	Sgl. Act. Diesel	35-60	17,640	108.12	-	45,200	20	
150,000	Raymond	60X	Sgl. Act. Steam	60	60,000	30	165	85,000	22-6 7/8	
*120,000	Vulcan	340	Sgl. Act. Steam/Air	60	40,000	36	120	87,673	18-7	
113,488	Vulcan	400C	Diff. Act. Steam/Air	100	40,000	16.5	150	83,000	16-3	
105,600	Kobe	K-60	Sgl. Act. Diesel	42-60	13,200	96	-	37,500	24-3	
100,000	Raymond	40X	Sgl. Act. Steam	64	40,000	30	135	62,000	19-1	
92,540	Delmag	D-46	Sgl. Act. Diesel	37-53	10,120	128.75	-	19,950	14-11 5/8	
91,100	Kobe	K-45	Sgl. Act. Diesel	39-60	9,900	110	-	25,600	18-6	
90,000	Vulcan	030	Sgl. Act. Steam/Air	55	30,000	36	150	53,420	16-4	
87,000	Delmag	D44	Sgl. Act. Diesel	37-56	9,460	110	-	22,400	15-10 1/8	
81,250	Raymond	8/0	Sgl. Act. Steam	33-38	25,000	39	135	34,000	19-4	
79,000	Kobe	K-42	Sgl. Act. Diesel	40-60	9,260	102	-	24,000	18-6	
75,000	Raymond	30X	Sgl. Act. Steam	70	30,000	30	135	52,000	19-1	
73,780	Delmag	D-36	Sgl. Act. Diesel	37-53	7,940	128.75	-	17,781	14-11 5/8	
70,800	Kobe	K-35	Sgl. Act. Diesel	39-60	7,700	110	-	18,700	17-8	
60,100	Kobe	K-32	Sgl. Act. Diesel	40-60	7,050	102	-	17,750	17-8	
60,000	MKT	S20	Sgl. Act. Steam/Air	60	20,000	36	150	38,650	18-5	Yes
60,000	Vulcan	020	Sgl. Act. Steam/Air	60	20,000	36	120	41,670	15-7	
59,900	MKT	DE70B/50B	Sgl. Act. Diesel	40-50	7,000	126	-	14,600	15-10	
56,900	Raymond	22X	Sgl. Act. Steam	58	22,050	31	135	31,750	17-8	
56,875	Raymond	5/0	Sgl. Act. Steam	44	17,500	39	135	26,450	16-9	
54,900	Union	00	Dbl. Act. Steam/Air	85	6,000	36	80	21,000	15-2	
54,200	Delmag	D-30	Sgl. Act. Diesel	39-60	6,600	99	-	12,346	14-2 1/8	
50,700	Kobe	K-25	Sgl. Act. Diesel	39-60	5,510	110	-	13,100	17-6	
50,200	Vulcan	200C	Diff. Act. Steam/Air	98	20,000	15.5	142	39,000	13-11	
48,750	Raymond	4/0	Sgl. Act. Steam	46	15,000	39	120	23,800	16-1	
48,750	Raymond	150C	Diff. Act. Steam	95-105	15,000	18	120	32,500	15-9	
48,750	Vulcan	016	Sgl. Act. Steam/Air	60	16,250	36	120	30,250	13-11	
45,000	ICE	660	Dbl. Act. Diesel	84	7,564	71	-	23,423	15-8	
44,000	MKT	MS-500	Sgl. Act. Steam/Air	40-50	11,000	48	115	16,600	16-8	
43,400	Vulcan	03N100	Sgl. Act. Diesel	50-60	5,280	97.5	-	12,760	15-1	
42,500	MKT	DE70B/50B	Sgl. Act. Diesel	40-50	5,000	126	-	12,600	15-10	
42,500	MKT	DE50B	Sgl. Act. Diesel	40-50	5,000	126	-	12,000	14-9	
42,000	Vulcan	014	Sgl. Act. Steam/Air	60	14,000	36	110	27,500	13-11	
41,300	Kobe	K-22	Sgl. Act. Diesel	40-60	4,850	102	-	12,350	17-6	
40,625	Raymond	000	Sgl. Act. Steam	48	12,500	39	120	21,225	15-7	
40,625	Raymond	125CX	Diff. Act. Steam	110-120	15,000	15	120	32,800	15-9	
40,000	MKT	DA-55B	Sgl. Act. Diesel	48	5,000	96	-	19,630	17-4	
39,780	Delmag	D-22	Sgl. Act. Diesel	40-60	4,840	99	-	11,070	14-2 1/8	
38,800	MKT	MS350	Sgl. Act. Steam/Air	40-50	7,716	48	105	10,950	14-4	
38,000	MKT	DA-55B	Dbl. Act. Diesel	80	5,000	-	-	19,630	17-4	
37,500	MKT	S14	Sgl. Act. Steam/Air	60	14,000	30	100	31,700	16-7	Yes
36,000	Vulcan	140C	Diff. Act. Steam/Air	103	14,000	15.5	140	27,984	12-3	
32,885	Vulcan	100C	Diff. Act. Steam/Air	103	10,000	16.5	140	22,200	14-0	
32,549	Vulcan	04N100	Sgl. Act. Diesel	50-60	3,960	97.5	-	9,845	15-1	
32,500	Raymond	00	Sgl. Act. Steam	50	10,000	39	110	18,550	15-0	
27,100	Delmag	D-15	Sgl. Act. Diesel	40-60	3,300	129.94	-	6,615	13-11	
26,300	ICE	520	Dbl. Act. Diesel	80-84	5,070	62.19	-	12,545	13-6	
26,000	Vulcan	08	Sgl. Act. Steam/Air	50	8,000	39	83	16,750	14-10	
26,000	Vulcan	85C	Diff. Act. Steam/Air	111	8,525	16.5	128	19,020	12-7	
25,000	Kobe	K-13	Sgl. Act. Diesel	40-60	2,810	106	-	8,000	16-8	
24,600	Vulcan	01N100	Sgl. Act. Diesel	50-60	3,000	98	-	7,645	15-8	
24,450	Raymond	80CH	Hydraulic	110-120	8,000	16.5	-	17,780	11-10 1/4	
24,450	Vulcan	80C	Diff. Act. Steam/Air	111	8,000	16.5	120	17,885	12-1	
24,450	Raymond	80C	Diff. Act. Steam/Air	105-115	8,000	16.5	120	-	12-9	
24,375	Raymond	0	Sgl. Act. Steam	52	7,500	39	110	16,100	15-0	
23,800	MKT	DE30B/20B	Sgl. Act. Diesel	40-50	2,800	120	-	7,250	15-4	
23,800	MKT	DA356	Sgl. Act. Diesel	40-50	2,800	120	-	10,800	17-0	
22,610	Delmag	D-12	Sgl. Act. Diesel	40-60	2,750	99	-	6,050	13-11	

TABLE 4 (Continued)

Rated Energy (Ft.-Lb.)	Mfgr.	Model	Type	Speed (Blows/Min.)	Ram Weight (Lbs.)	Stroke (In.)	Air or Stream (PSI)	Net Weight (Lbs.)	Length (Ft.-In.)	Submers-ible
22,050	Union	0A	Dbt. Act. Steam/Air	90	5,000	21	80	17,000	14-1 3/4	
21,000	MKT	DA-35C	Dbl. Act. Diesel	78-82	2,800	-	-	10,800	17-0	
19,500	Raymond	1-S	Sgl. Act. Steam	58	6,500	36	104	12,500	12-9	
19,500	Raymond	65-C	Diff. Act. Steam	100-110	6,500	16	120	14,675	11-8	
19,500	Raymond	65-CH	Hydraulic	128-136	6,500	16	-	14,615	11-11 5/8	
19,500	Vulcan	06	Sgl. Act. Steam/Air	60	6,500	36	100	11,200	12-9	
19,500	Vulcan	106 (Heavy Ram)	Sgl. Act. Steam/Air	60	6,500	36	100	11,200	12-9	
19,200	Vulcan	65C	Diff. Act. Steam/Air	117	6,500	15.5	150	14,886	12-1	
19,150	MKT	11B3	Dbl. Act. Steam/Air	95	5,000	19	100	14,000	11-1 1/2	Yes
18,200	ICE	440	Dbl. Act. Diesel	86-90	4,000	54.6	-	10,300	16-3	
17,000	MKT	DE30B/20B	Sgl. Act. Diesel	40-50	2,000	120	-	6,450	15-4	
15,100	Vulcan	50C	Diff. Act. Steam/Air	120	5,000	15.5	120	11,782	11-0	
15,000	Raymond	1	Sgl. Act. Steam	60	5,000	36	80	11,000	12-9	
15,000	Raymond	15M	Diff. Act. Steam	75-90	5,000	18	120	10,305	20-10	
15,000	Vulcan	1	Sgl. Act. Steam/Air	60	5,000	36	80	9,700	12-9	
15,000	Vulcan	106 (Light Ram)	Sgl. Act. Steam/Air	60	5,000	36	80	9,700	12-9	
13,100	MKT	10B3	Dbl. Act. Steam/Air	105	3,000	19	100	10,850	9-2	Yes
13,100	Union	1	Dbl. Act. Steam/Air	103	1,850	21	80	10,500	9-3 1/2	
10,020	Union	1A	Dbl. Act. Steam/Air	120	1,600	18	80	10,500	8-il	
9,900	MKT	DE-10	Sgl. Act. Diesel	48	1,100	108	-	3,518	12-2	
9,050	Delmag	D-5	Sgl. Act. Diesel	40-60	1,100	99	-	2,730	12-6	
8,800	MKT	DA15B	Sgl. Act. Diesel	40-50	1,100	120	-	6,000	14-8	
8,750	MKT	9B3	Dbl. Act. Steam/Air	145	1,600	17	100	7,000	8-3 3/4	Yes
8,680	Union	1 1/2A	Dbl. Act. Steam/Air	125	1,500	18	80	9,200	8-10 1/2	
8,200	MKT	DA15B	Dbl. Act. Diesel	84-90	1,100	-	-	6,000	14-8	
8,100	ICE	180	Dbl. Act. Diesel	90-95	1,725	55.68	-	4,550	11-3 1/8	
7,260	Vulcan	2	Sgl. Act. Steam/Air	70	3,000	29	80	6,700	11-7	
7,260	Vulcan	30C	Diff. Act. Steam/Air	133	3,000	10.5	120	7,036	8-11	
5,755	Union	2	Dbl. Act. Steam/Air	145	1,025	16	80	6,600	7-10	
5,750	Vulcan	DGH-900 (Mounted Hammer)	Diff. Act. Steam/Air	360	900	10	120	5,000	6-9	
4,390	Union	3A	Dbl. Act. Steam/Air	150	820	13.5	80	5,200	7-7 1/4	
4,150	MKT	7	Dbl. Act. Steam/Air	225	800	9.5	100	5,000	6-0 1/2	
4,000	Vulcan	DGH 900 (Free Hammer)	Diff. Act. Steam/Air	328	900	10	78	5,000	6-9	
3,660	Union	3	Dbl, Act. Steam/Air	160	700	14	80	4,700	6-9	
3,630	Delmag	D-4	Sgl. Act. Diesel	50-60	836	-	-	1,360	7-9	
26,000	Vulcan	85C	Diff. Act. Steam/Air	111	8,525	16.5	128	19,020	12-7	
2,500	MKT	6	Dbl. Act. Steam/Air	275	400	8.75	100	2,900	5-3 1/8	
2,100	Union	4	Dbl. Act. Steam/Air	200	370	12	80	2,800	5-6	
1,815	Delmag	D-2	Sgl. Act. Diesel	60-70	484	-	-	792	6-8 3/4	
1,010	Union	5	Dbl. Act. Steam/Air	250	210	9	80	1,625	4-6 3/4	
1,000	MKT	5	Dbl. Act. Steam/Air	300	200	7	100	1,500	4-9	
643	Vulcan	DGH 100 (Mounted Hammer)	Diff. Act. Air	505	100	6	100	803	4-6	
445	Union	6	Dbl. Act. Steam/Air	340	100	7	80	910	3-10 1/2	
386	Vulcan	DGH 100 (Free Hammer)	Diff. Act. Air	303	100	6	60	803	4-6	
320	Union	7A	Dbl. Act. Steam/Air	400	80	6	80	540	3-7 1/2	
210	Union	8	Dbl. Act. Steam/Air	over 450	40	6.5	80	200	2-6	
90	Union	9	Dbl. Act. Steam/Air	over 550	25	4	80	100	2-1	

*Vulcan Hammers can go as high as 1,800,000 ft.-lbs. rated energy.

TABLE 5
Data on Discontinued Models of Impact Type Pile Hammers

Rated Energy (Ft.-Lb.)	Mfgr.	Model	Type	Speed (Blows/Min.)	Ram Weight (Lbs.)	Stroke (In.)	Air or Stream (PSI)	Net Weight (Lbs.)	Length (Ft.-In.)	Submersible
180,000	Vulcan	060	Sgl. Act. Steam/Air	62	60,000	36	130	121,000	18-6	
180,000	MKT	OS60	Sgl. Act. Steam/Air	55	60,000	36	125	141,150	26-4	Yes
120,000	MKT	OS40	Sgl. Act. Steam/Air	55	40,000	36	125	111,000	22-10	Yes
90,000	MKT	OS30	Sgl. Act. Steam/Air	60	30,000	36	150	50,500	21-6	
63,000	MKT	DE70	Sgl. Act. Diesel	-	7,000	108	-	12,000	15-10	
60,000	MKT	OS20	Sgl. Act. Steam/Air	60	20,000	36	125	40,000	18-0	
50,200	Vulcan	20000	Diff. Act. Steam/Air	98	20,000	15 1/2	142	39,050	-	
36,000	Vulcan	14000	Diff. Act. Steam/Air	103	14,000	15 1/2	140	27,984	-	
32,500	MKT	S10	Sgl. Act. Steam/Air	55	10,000	39	80	22,380	14-1	Yes
30,225	Vulcan	OR	Sgl. Act. Steam/Air	80	9,300	39	100	18,050	15-0	
30,100	MKT	DE-30	Sgl. Act. Diesel	48	2,800	129	-	9,075	15-0	
26,000	MKT	C-8	Dbl. Act. Steam/Air	77-85	8,000	20	100	18,750	9-9	Yes
26,000	MKT	S8	Sgl. Act. Steam/Air	55	8,000	39	80	18,300	14-4	Yes
25,200	MKT	DE-30B	Sgl. Act. Diesel	-	2,800	108	-	7,300	15-4	
24,450	Vulcan	8000	Diff. Act. Steam	111	8,000	16 1/2	120	17,885	-	
24,450	Vulcan	8M	Diff. Act. Steam/Air	111	8,000	16 1/2	120	17,900	-	Yes
24,375	Vulcan	0	Sgl. Act. Steam/Air	80	7,500	39	80	16,250	15-0	
22,400	MKT	DA-35B	Sgl. Act. Diesel	48	2,800	96	-	10,950	17-0	
22,080	MKT	11-B-2	Dbl. Act. Steam/Air	120	3,625	20	100	12,195	-	
21,000	MKT	DA-35B	Dbl. Act. Diesel	82	2,800	-	-	10,950	17-0	
19,850	Union	0	Dbl. Act. Steam/Air	110	3,000	24	80	14,500	10-10 3/4	
19,565	Vulcan	1C65	Dbl. Act. Int. Combustion	100	6,500	15 1/2	-	14,500	4-3	
18,800	MKT	DE-20	Sgl. Act. Diesel	48	2,000	113	-	6,325	13-3	
16,250	MKT	S5	Sgl. Act. Steam/Air	60	5,000	39	80	12,460	13-3	Yes
16,000	MKT	C-5	Dbl. Act. Steam/Air	100-110	5,000	18	100	11,880	8-9	Yes
15,100	Vulcan	5000	Diff. Act. Steam/Air	120	5,000	15 1/2	120	11,782	-	
15,100	Vulcan	5M	Diff. Act. Steam/Air	120	5,000	15 1/2	120	11,300	-	Yes
15,000	MKT	10-B-2	Dbl. Act. Steam/Air	115	2,500	20	100	9,162	-	
9,000	MKT	S-3	Single Act. Steam/Air	65	3,000	36	80	9,030	11-4	Yes
9,000	MKT	C-3	Dbl. Act. Steam/Air	130-140	3,000	16	100	8,500	7-9 1/2	Yes
8,200	MKT	9-B-2	Dbl. Act. Steam/Air	140	1,500	16	100	6,315	-	
7,260	Vulcan	3000	Diff. Act. Steam/Air	133	3,000	12 1/2	120	7,036	-	
7,260	Vulcan	3M	Diff. Act. Steam/Air	133	3,000	12 1/2	120	7,590	-	Yes
6,000	MKT	9	Dbl. Act. Steam/Air	-	1,250	12	90	-	-	
3,600	Vulcan	1800	Diff. Act. Steam/Air	150	1,800	10 1/2	120	4,139	-	
3,600	Vulcan	18C	Diff. Act. Steam/Air	150	1,800	10 1/2	120	4,139	8-3 3/8	
3,200	MKT	6.5	Dbl. Act. Steam/Air	280	600	8 3/8	100	4,390	-	
2,180	Vulcan	1100	Diff. Act. Steam/Air	181	1,100	9	-	2,939	-	
1,125	Vulcan	600	Diff. Act. Steam/Air	225	600	7 3/4	-	2,357	-	
-	MKT	0	Dbl. Act. Steam/Air	-	5 1/4	4 3/4	100	95	-	
1,010	Union	5	Dbl. Act. Steam/Air	250	210	9	80	1,625	4-6 3/4	
1,000	MKT	5	Dbl. Act. Steam/Air	300	200	7	100	1,500	4-9	
1,000				550			100 Std.			
750	Vulcan	09E100	Dbl. Act. Steam/Air	413	800	2 1/8	75 Min.	5,460	10-7	
1,500				825			150 Max.			
500				550			100 Std.			
375	Vulcan	08E100	Dbl. Act. Steam/Air	413	400	2	75 Min.	2,850	9-1	
750				825			150 Max.			
445	Union	6	Dbl. Act. Steam/Air	340	100	7	80	910	3-10 1/2	
320	Union	7A	Dbl. Act. Steam/Air	400	80	6	80	540	3-7 1/2	
250				550			100 Std.			
188	Vulcan	07E100	Dbl. Act. Steam/Air	413	200	2	75 Min.	1,500	7-8	
375				825			150 Max.			
210	Union	8	Dbl. Act. Steam/Air	Over 450	40	6 1/2	80	200	2-6	
90	Union	9	Dbl. Act. Steam/Air	Over 550	25	4	80	100	2-1	
-	MKT	3	Dbl. Act. Steam/Air	400	68	5.75	100	675	4-9 3/4	
-	MKT	2	Dbl. Act. Steam/Air	500	48	7.25	100	343	2-8 3/4	
-	MKT	1	Dbl. Act. Steam/Air	500	21	3.75	100	145	3-6 7/8	

TABLE 6
Data on Impact Type Pile Extractors

Rated Energy (Ft.-Lb.)	Mfgr.	Model	Type	Speed (Blows/Min.)	Ram Weight (Lbs.)	Stroke (In.)	Air or Stream (PSI)	Net Weight (Lbs.)	Length (Ft.-In.)
54,900	Union	00	Dbl. Act. Steam/Air	85	6,000	36	80	21,000	15-2
22,050	Union	0A	Dbl. Act. Steam/Air	90	5,000	21	80	17,000	14-1 3/4
19,850	Union	0*	Dbl. Act. Steam/Air	110	3,000	24	80	14,500	10-10 3/4
13,100	Union	1	Dbl. Act. Steam/Air	130	1,850	21	80	10,500	9-3 1/2
10,020	Union	1A	Dbl. Act. Steam/Air	120	1,600	18	80	10,500	8-11
8,680	Union	1 1/2A	Dbl. Act. Steam/Air	125	1,500	18	80	9,200	8-10 1/2
6,000	MKT	9*	Dbl. Act. Steam/Air	-	1,250	12	90	-	-
5,755	Union	2	Dbl. Act. Steam/Air	145	1,025	16	80	6,600	7-10
4,390	Union	3A	Dbl. Act. Steam/Air	150	820	13 1/2	80	5,200	7-7 1/4
4,150	MKT	7	Dbl. Act. Steam/Air	225	800	9 1/2	100	5,000	6-0 1/2
3,660	Union	3	Dbl. Act. Steam/Air	160	700	14	80	4,700	6-9
3,600	Delmag	P-14	Sgl. Act. Diesel	100-135	-	-	-	5,280	8-9 1/2
2,500	MKT	6	Dbl. Act. Steam/Air	275	400	8 3/4	100	2,900	5-3 1/8
2,100	Union	4	Dbl. Act. Steam/Air	200	370	12	80	2,800	5-6
1,640	Vulcan	1200-A		530	1,200	2 1/8	100 Std.	9,200	9-2
1,230	Vulcan	10E100	Dbl. Act. Steam/Air	398	1,200	2 1/8	75 Min.	9,200	12-6
2,460				795			150 Max.		
1,010	Union	5	Dbl. Act. Steam/Air	250	210	9	80	1,625	4-6 3/4
1,000	MKT	5	Dbl. Act. Steam/Air	300	200	7	100	1,500	4-9
1,000	MKT	E4	Dbl. Act. Steam/Air	400	400	3	125	4,400	10-5
1,000	Vulcan	800-A		550	800	2 1/8	200 Std.	5,460	7-10
750	Vulcan	09E100	Dbl. Act. Steam/Air	413	800	2 1/8	75 Min.	5,460	10-7
1,500				825			150 Max.		
700	MKT	E2	Dbl. Act. Steam/Air	450	200	3	125	2,600	8-4
500	Vulcan	400-A		550	400	2	100 Std.	2,850	6-8
375	Vulcan	08E100	Dbl. Act. Steam/Air	413	400	2	75 Min.	2,850	9-1
750				825			150 Max.		
445	Union	6	Dbl. Act. Steam/Air	340	100	7	80	910	3-10 1/2
320	Union	7A	Dbl. Act. Steam/Air	400	80	6	80	540	3-7 1/2
250				550			100 Std.		
188	Vulcan	07E100	Dbl. Act. Steam/Air	413	200	2	75 Min.	1,500	7-8
375				825			150 Max.		
210	Union	8	Dbl. Act. Steam/Air	Over 450	40	6 1/2	80	200	2-6
90	Union	9	Dbl. Act. Steam/Air	Over 550	25	4	80	100	2-1
-	MKT	2	Dbl. Act. Steam/Air	500	48	4 1/4	100	343	2-8 3/4

*Discontinued.

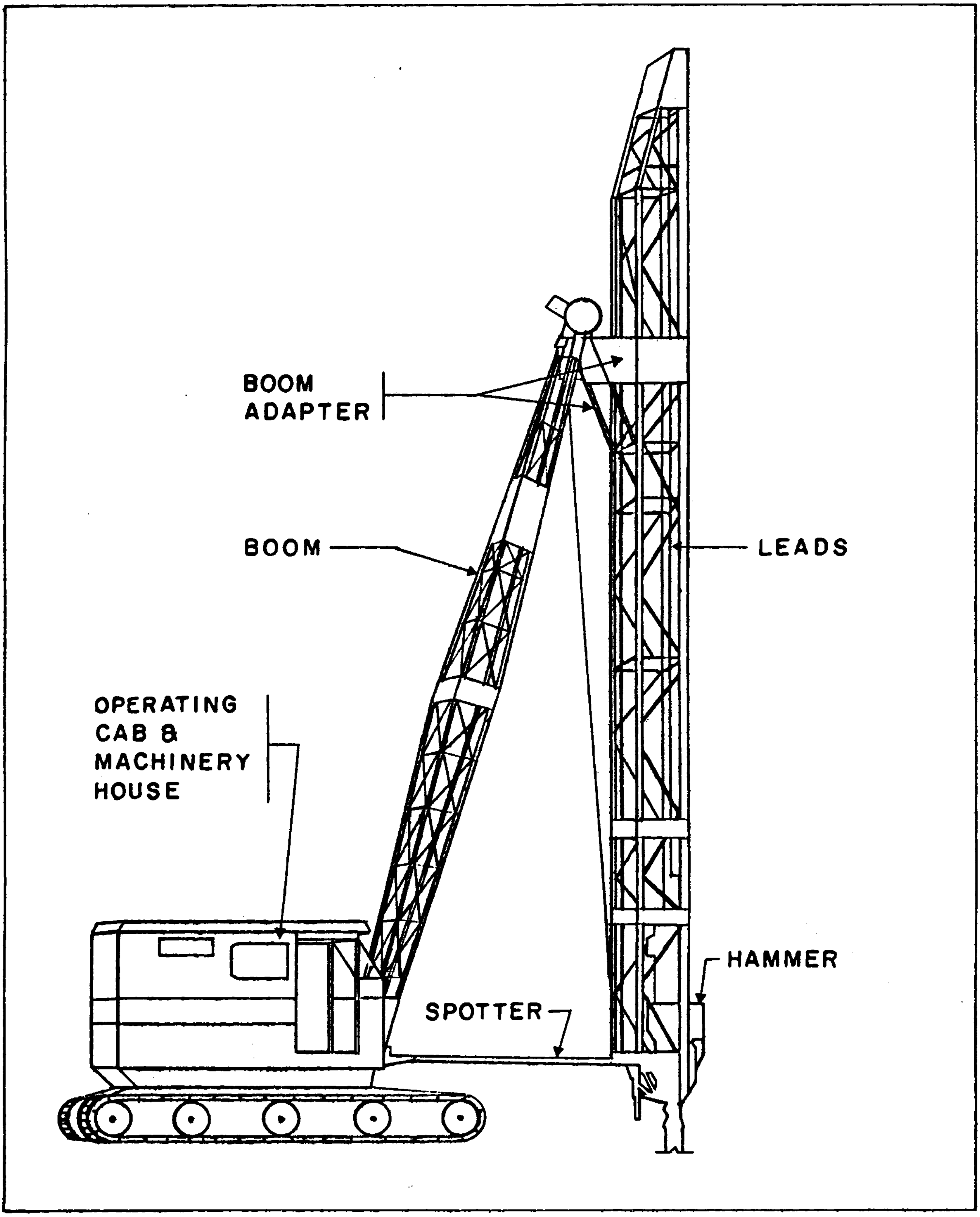


FIGURE 4
Commercial Crane (Crawler) Adapted for Pile Driving

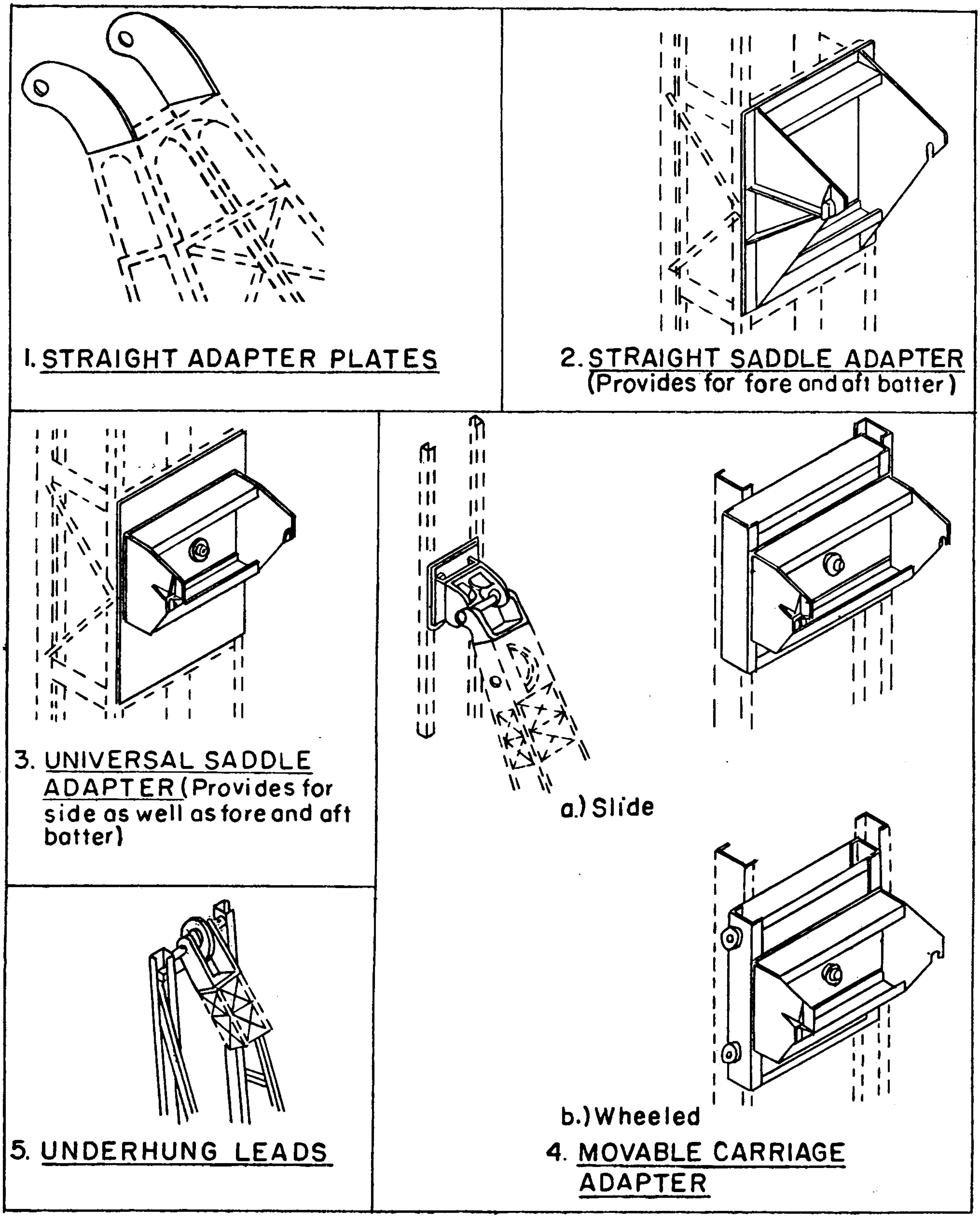


FIGURE 5
Typical Boom Adapters

3. SELECTING THE TYPE OF LEADS.

a. Function. Leads serve as tracks along which the hammer travels and as guides for positioning and steadying the pile during the driving process. The best leads, however, are of no avail in this regard unless the pile driving rig is on a solid level base, and mats should be provided under the rig whenever the ground is not firm. Further, leads must be carefully plumbed and positioned before driving and the center line of the pile positioned concentrically within the leads.

b. Characteristics of Leads. (See Figure 6.)

(1) Fixed Leads. Suitable for plumb piles only.

(2) Swinging (Hanging) Leads. Hung from a crane boom with a single line. In use, this lead is spotted on the ground at the pile location, generally with stabbing points attached, and held plumb or at the desired batter with the supporting crane line. Short swinging leads are often used to assist in driving steel sheet piling.

(a) Advantages:

(i) Lightest, simplest and least expensive.

(ii) With stabbing points secured in ground this lead is free to rotate sufficiently to align hammer with pile without precise alignment of crane with pile.

(iii) Because these leads are generally 15 to 20 feet shorter than the boom, crane can reach out farther, assuming the crane capacity is sufficient.

(iv) Can drive in a hole or ditch or over the edge of an excavation.

(v) For long lead and boom requirements, the lead weight can be supported on the ground while the pile is lifted into place without excessively increasing the working load.

(b) Disadvantages:

(i) Requires 3-drum crane (1 for lead, 1 for hammer, 1 for pile) or 2-drum crane with lead hung on sling from boom point.

(ii) Because of crane line suspension, precise positioning of lead with pile head is difficult and slow.

(iii) Difficult to control twisting of lead if stabbing points are not secured to ground.

(iv) It is more difficult to position crane with these leads than with any other. Operator must rely on balance while center of gravity continues to move.

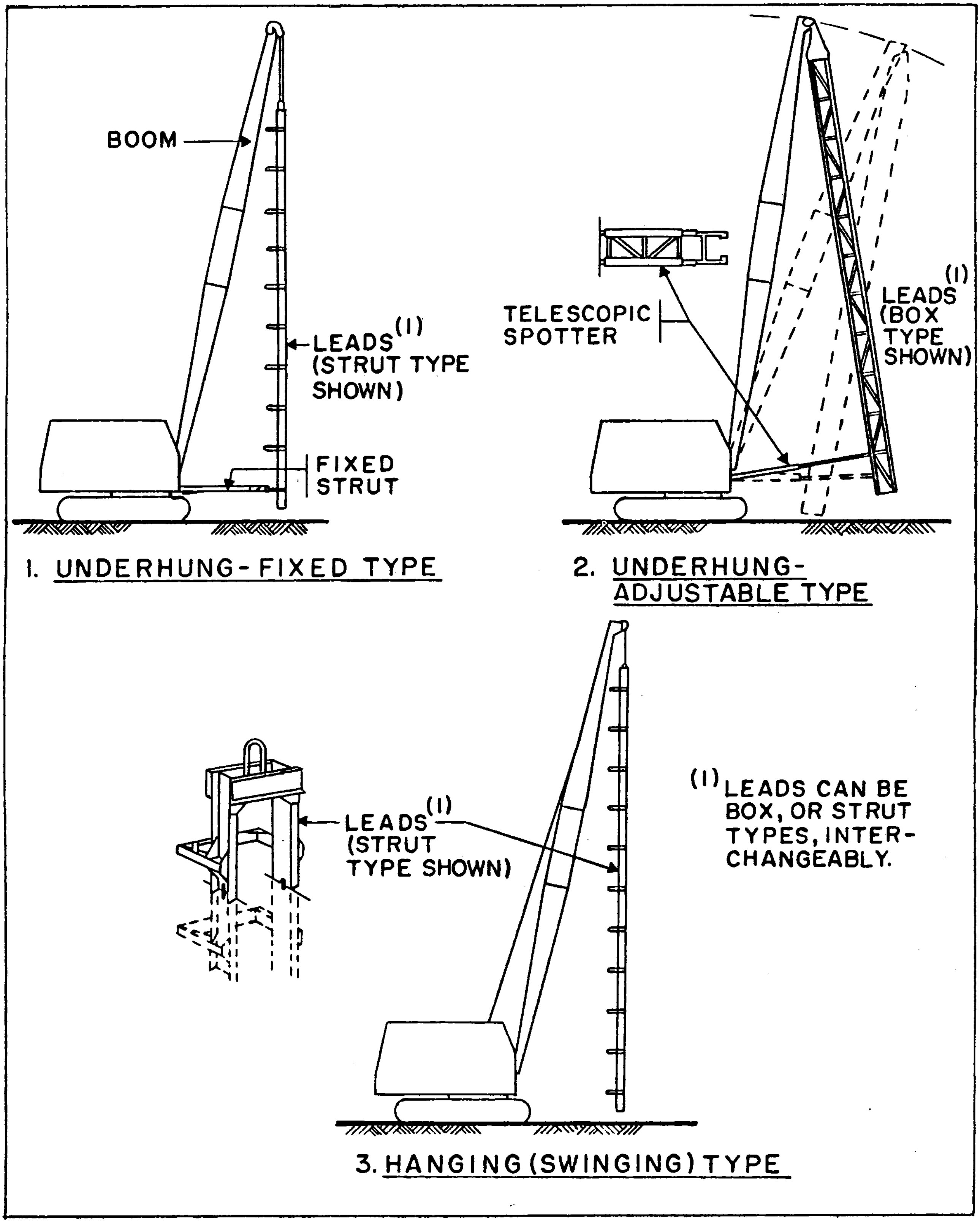


FIGURE 6 (1 of 3)
Types of Leads

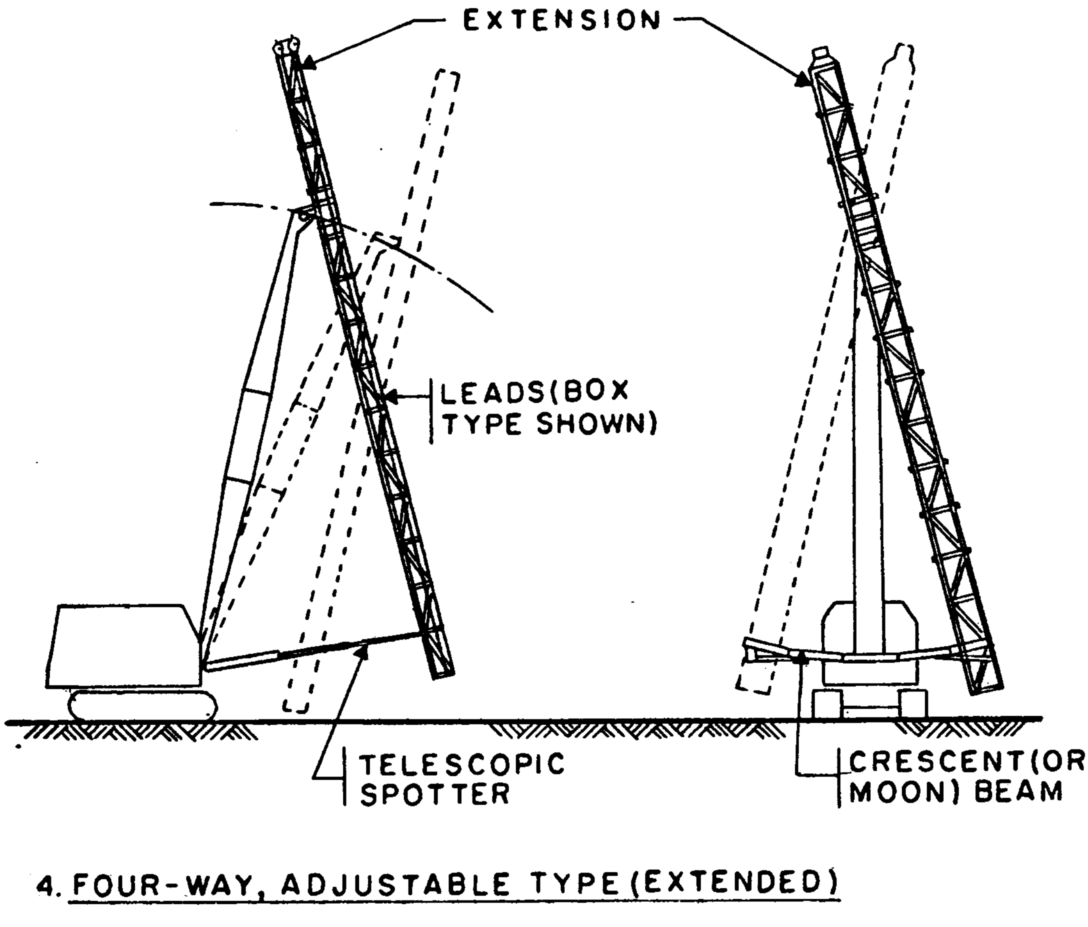


FIGURE 6 (2 of 3)
Types of Leads

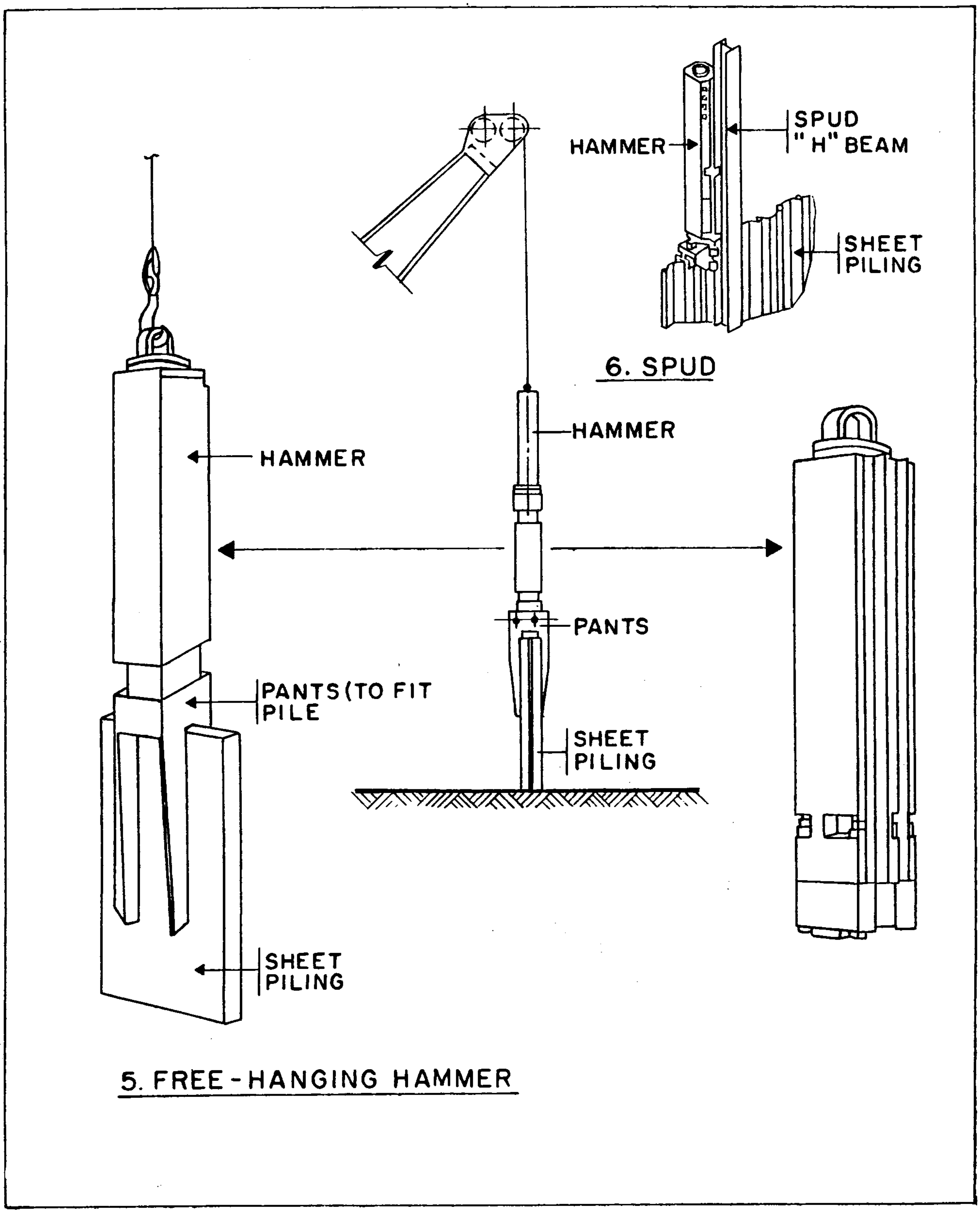


FIGURE 6 (3 of 3)
Types of Leads

(3) Underhung Lead. Pinned to the boom point and connected to the crane cab by either a rigid bottom brace for vertical driving or an adjustable spotter for fore and aft driving.

(a) Advantages:

(i) Lighter and generally less expensive than extended type lead.

(ii) Requires only 2-drum crane.

(iii) Accuracy in locating lead in vertical or fore and aft batter positions.

(iv) Rigid control of lead during positioning operation.

(v) Reduces rigging time in setting up and breaking down.

(vi) Utilizes sheave head in crane boom.

(b) Disadvantages:

(i) Cannot be used for side to side batter driving.

(ii) Length of pile limited by boom length since this type of lead cannot be extended above the boom point.

(iii) When the long leads dictate the use of a long boom, the working radius which results may be excessive for the capacity of the crane.

(4) Extended 4-Way Lead. Attached to the boom point with a swivel connection to allow batter in all directions when used with an adjustable spotter.

(a) Advantages:

(i) Requires only 2-drum crane.

(ii) Accuracy in locating lead in vertical position and all batter positions.

(iii) Rigid control of lead during positioning operation.

(iv) Compound batter angles can be set and accurately maintained.

(v) Allows use of short boom with resulting increase in capacity.

(vi) Boom can be lowered and leads folded under (for short-haul over the road and railroad travel) when crane of adequate capacity is used. This depends on the length of lead and boom and the configuration of the crane.

(b) Disadvantages:

(i) Heaviest and most expensive of the three basic lead types.

(ii) More troublesome to assemble.

(5) Free-Hanging Hammer (See Figure 6). Control of alignment of pile is difficult.

(6) Spud (See Figure 6). Pile is fitted with guides (jaws) to follow suspended "H" beam.

c. Design Requirements.

(1) Length. If practicable, provide leads of sufficient length to accommodate the longest pile required plus the necessary clearance for the pile hammer and fittings. (See Tables 4 to 6.)

(2) Width. The leads must be wide enough to accommodate the hammer. Braces are provided between the parallel members to keep the alignment for hammer travel. (See Tables 4 to 6.)

(3) Minimize weight to reduce required crane size, but check adequacy of strength allowing for rough handling and corrosion.

(4) Eliminate projections and snags to minimize line damage and personnel safety hazards.

d. Lead Accessories.

(1) Stabbing Points (Figure 7). For use with swinging leads.

(2) Cradle (Figure 8). For use where it is necessary to run the hammer down below the level of the rig into excavations, trenches, or water. Provide for lowering or raising by means of a separate line.

(3) Hairpin (Figure 8). Used to adapt a narrow hammer to wide leads.

(4) Telescope. Serves same purpose as hairpin, but built strong enough to extend beyond and carry hammer below bottom of leads.

(5) Pile Gate (Figure 8). Keeps lead centered over pile. In lieu of a pile gate, a template may be used. The template is highly effective and is the best device to use where accurate positioning of the pile is required.

(6) Pants, Skirt, Cage (Figure 8). Fasten to sides of pile hammer and extend below anvil block to keep free-hanging hammer centered upon and in alignment with pile.

(7) Sheave Head Assembly (Figure 8). For use with extended leads to carry hammer and pile lines over top of leads.

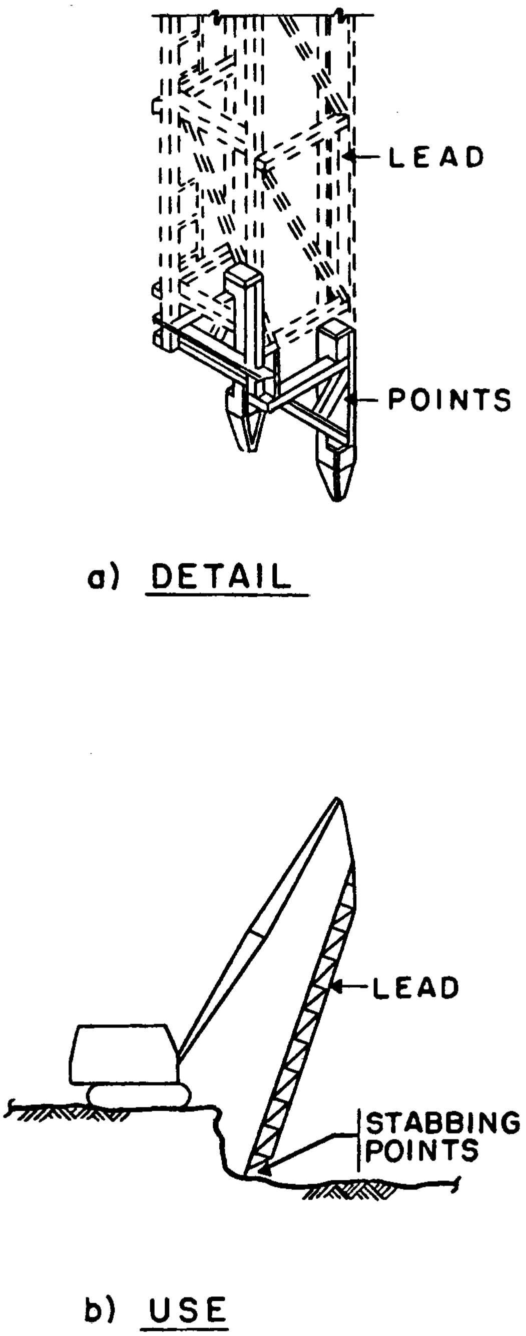


FIGURE 7
Leads--Stabbing Points

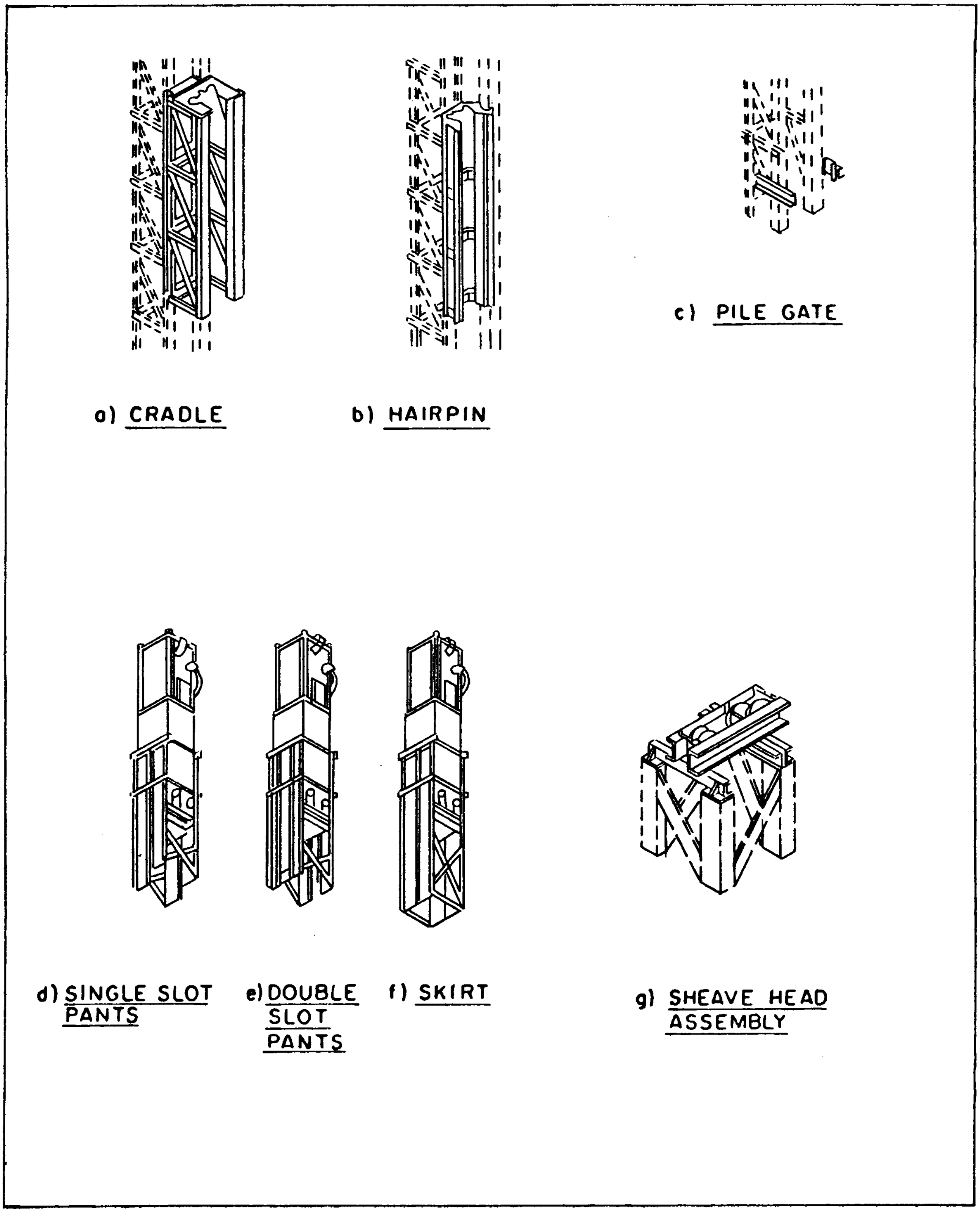


FIGURE 8
Miscellaneous Lead Accessories

(8) A special positioning device for sheet piling is shown in Figure 14.

e. Some Details.

(1) On floating rigs, brace leads laterally to reduce side whip when barge rolls.

(2) Avoid supporting weight of hanging leads on pile. During initial stage of driving, (when a long section of freestanding pile is in the leads) the weight may buckle the pile.

4. SELECTING THE POWER EQUIPMENT.

a. Power Requirements.

(1) Steam and air. See Tables 4 to 6 to obtain the requirements for steam and air for the various types and makes of hammers.

(2) Electric. For other than crane type rigs, where no outside source of power is available, a diesel electric (or gasoline electric) generator set of ample power is required for the operation of electric winches and for electric lighting.

b. Boilers. Boilers for steam operated pile hammers shall be the vertical fire or water-tube type. Essential requirements are portability, compactness, low initial cost, rapid steaming ability, and short chimney.

(1) Injector or Pump. Provide two injectors, or one injector and one fixed pump, the latter combination being preferable.

(2) Safety Valves. Safety valves should be spring loaded because boilers are often subject to vibrations.

c. Steam Generators. Steam generators for pile drivers shall be of the flash type to provide compactness, relatively simple operation. In general, incorporate dry steam and automatic control features.

d. Air Compressors. When operating hammers by air pressure, air compressor shall have a rated output consistent with power requirements of the hammer selected. Where practicable, compressors should be mounted directly on the pile driving rig.

5. SELECTING ACCESSORIES.

a. Bands.

(1) Concrete piles. Where hard driving conditions occur, metal bands may be provided to prevent spalling or shattering of the pile heads.

(a) Size of bands:

For square piles	Band size
Up to 12 inches	2 x 1/8 inch
12 to 15 inches	2-1/2 x 3/16 inches
Over 15 inches	3 x 1/4 inches

The cross section of bands may be reduced somewhat for round or octagonal piles.

(b) Number of bands: Use two or three bands according to the strength required; the first placed one inch clear of the head and the remainder at centers about equal to half the overall width of pile.

(c) Anchoring: The top band should be either anchored into the concrete or roughened on the inside to provide a good bond.

(2) Wood piles. Where hard driving conditions cause brooming of pile heads, such brooming may be minimized by the use of a steel band around the head of the pile or by wrapping the head with wire. Banding is preferred to wire wrappings. Hand-operated, commercial baling machines are used for this purpose.

b. Driving Shoes. Where hard driving conditions occur, the use of driving shoes on the tips of wood or concrete piles may be specified to assist in obtaining the required penetration without damaging the pile tip. See Figure 9 for types of shoes in common use. The use of shoes on timber piles is a matter of controversy. Opinions differ as to whether the shoe protects the pile tip or aggravates the damage potential by concentrating the resistant pressure in a localized area (or areas). Many engineers prefer banding the tips of timber piles to the use of shoes.

c. Driving Caps. Driving caps (anvils and driving heads) are used to distribute the blow from the hammer more uniformly to the head of the pile. They are made by manufacturers of pile hammers to suit their individual equipment and various types of piles. See Figure 10 for some typical forms. Knowledge of the hammer to be used and the type of pile to be driven determines the driving cap required.

d. Splices. See Figure 11 for types of splices available for use with various types of piles. Selection is a matter of individual preference. Any of the types shown can be made strong enough to develop the strength of the pile.

e. Followers. Use followers where leads do not permit running the hammer down below the level of the rig into excavations, trenches, or water, or where piles are to be driven below grade. See Figure 12 for types of followers. Selection, largely, is a matter of individual preference.

f. Mandrels. Internal mandrels are used to drive shells for some types of cast-in-place piles. After removal of the mandrel, the shell is filled with concrete. See Figure 13 for illustrations of some types of mandrels.

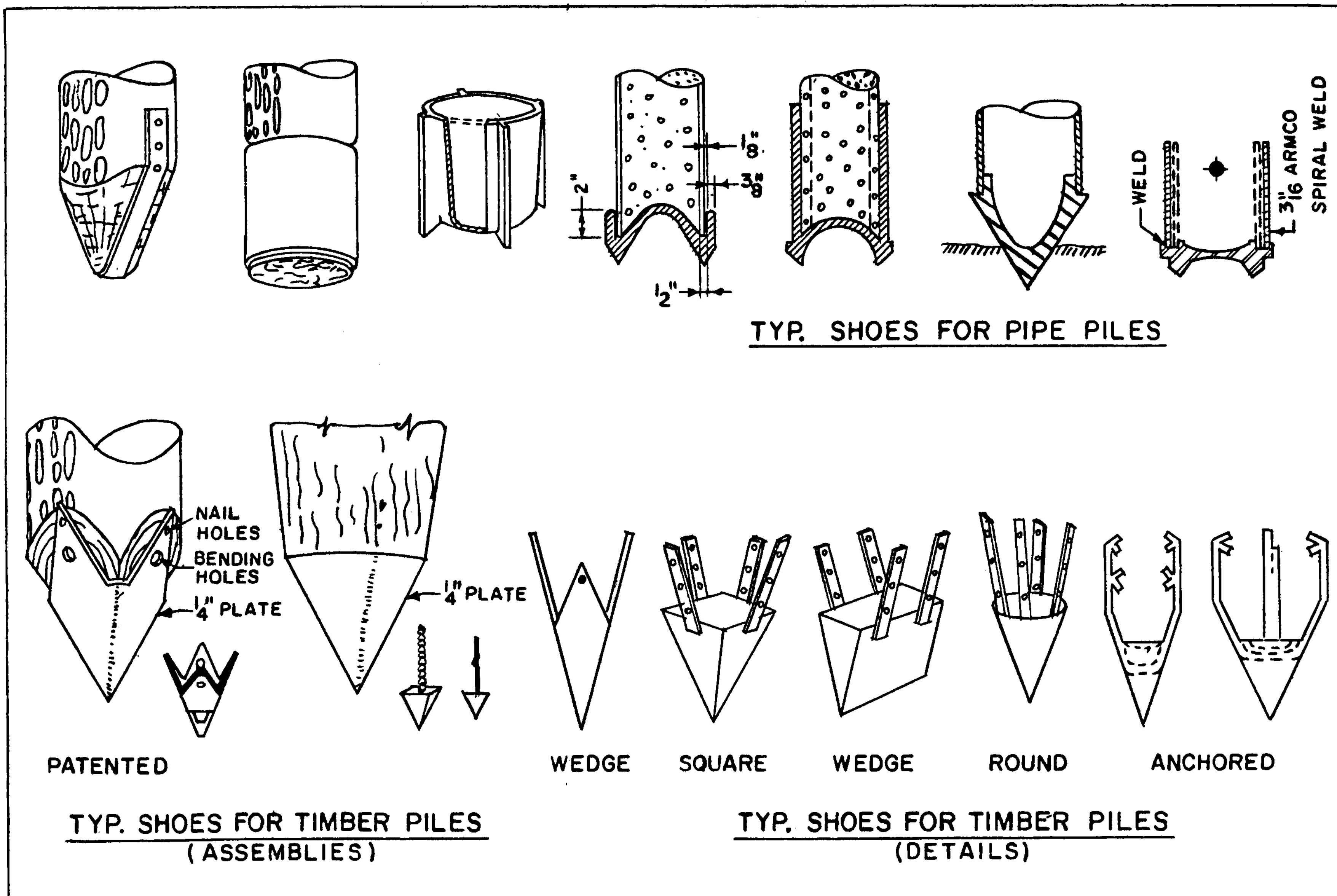


FIGURE 9 (1 of 2)
Typical Pile Shoes

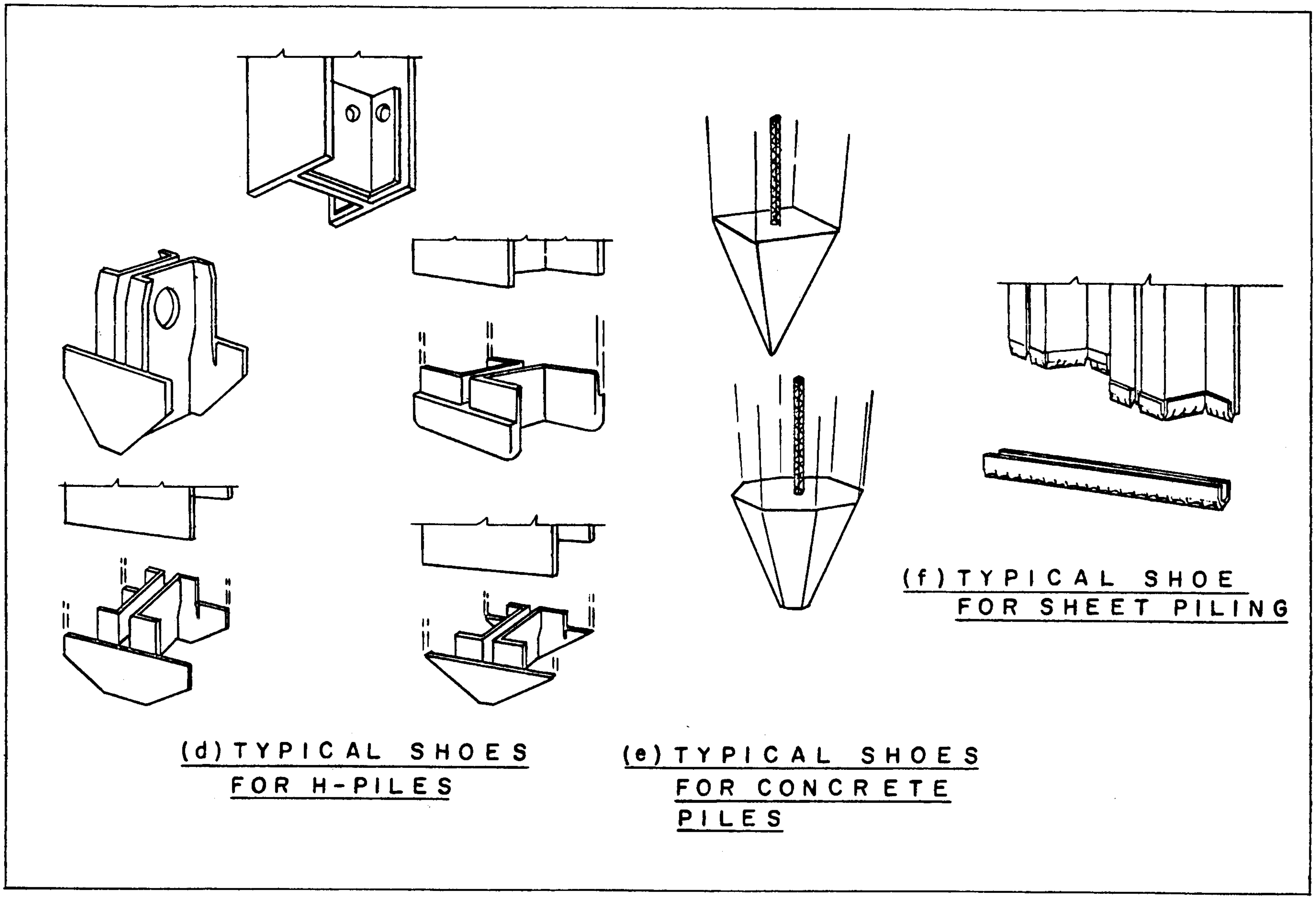


FIGURE 9 (2 of 2)
Typical Pile Shoes

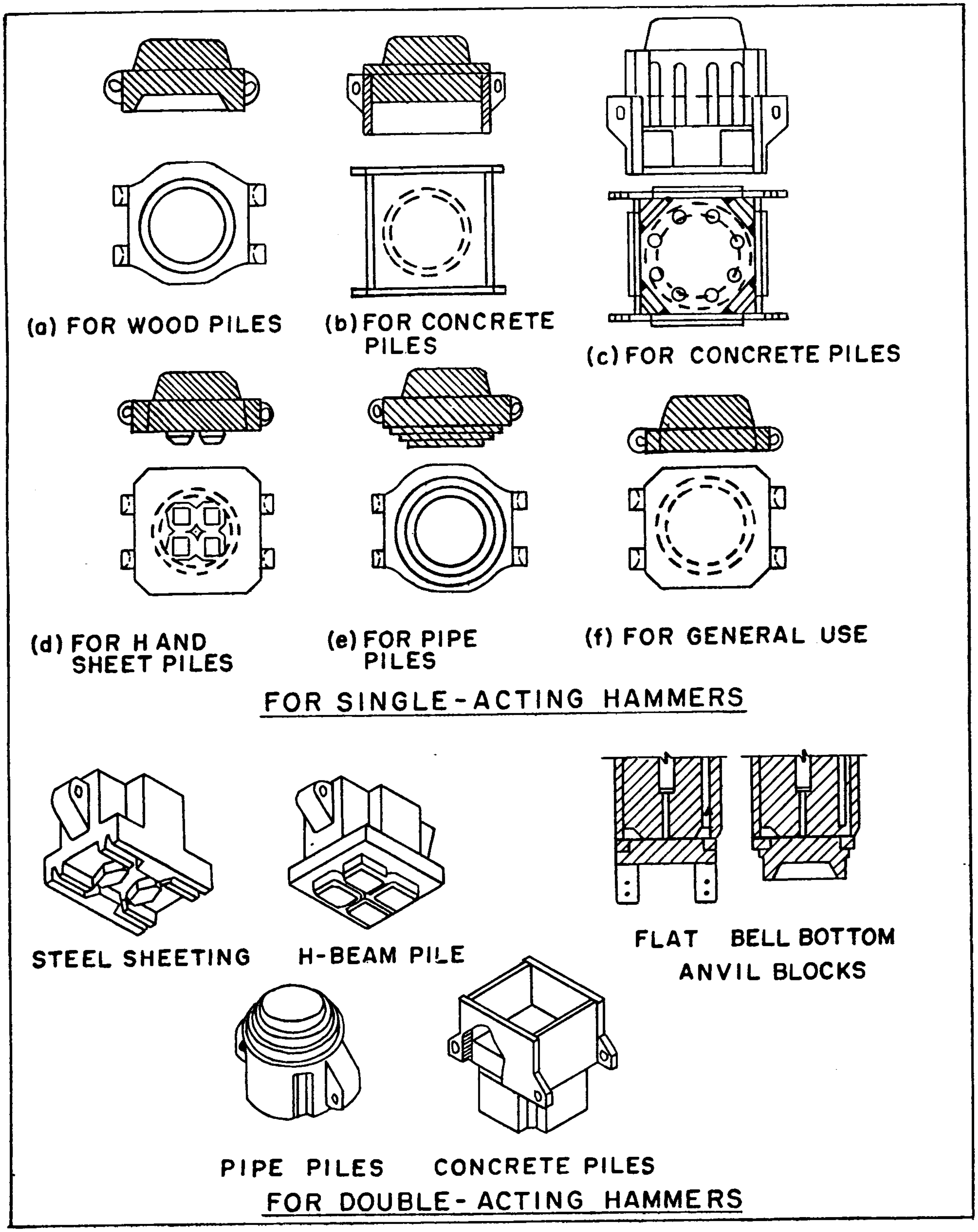


FIGURE 10
Typical Driving Caps

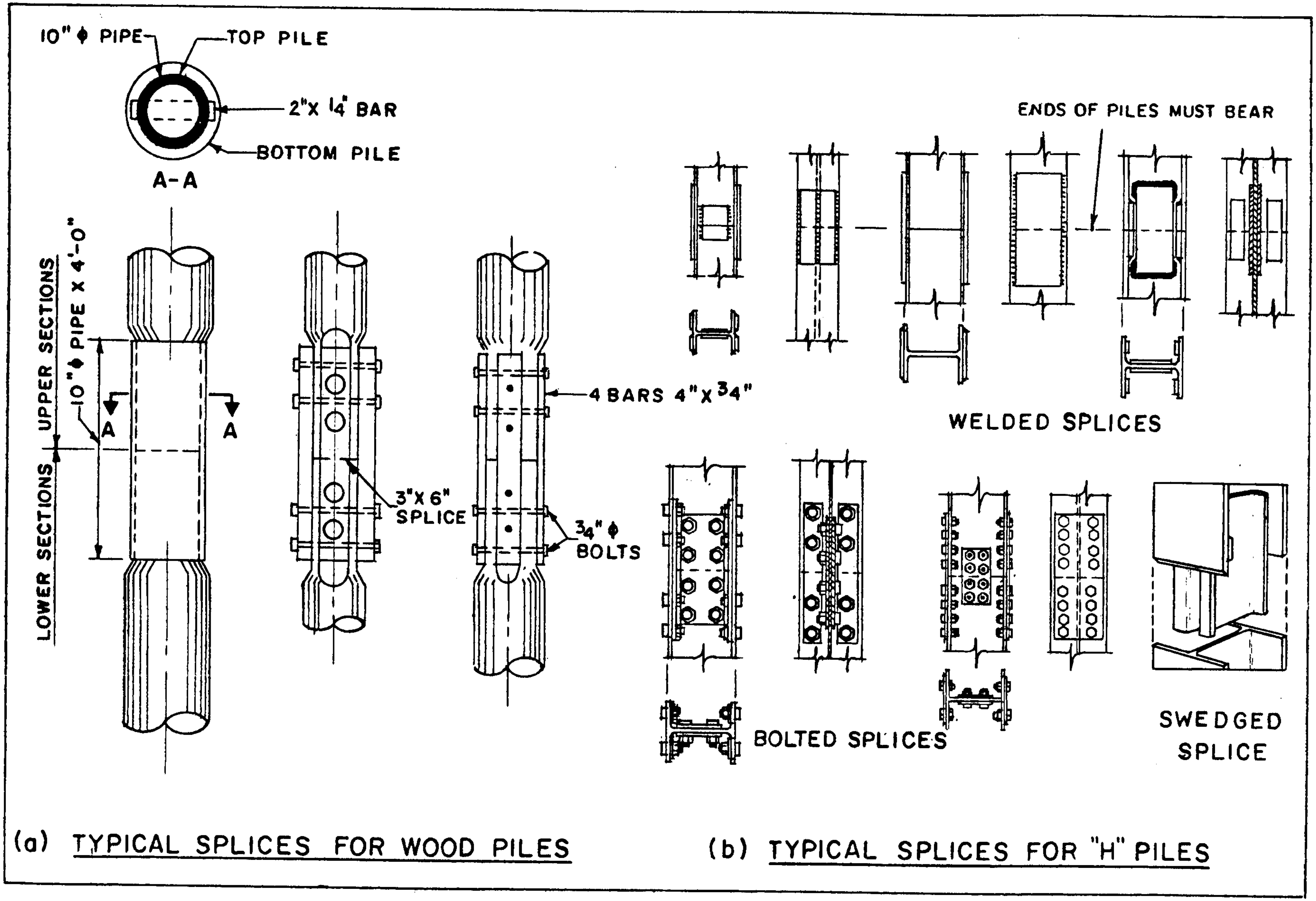


FIGURE 11 (1 of 2)
Typical Splices for Piles

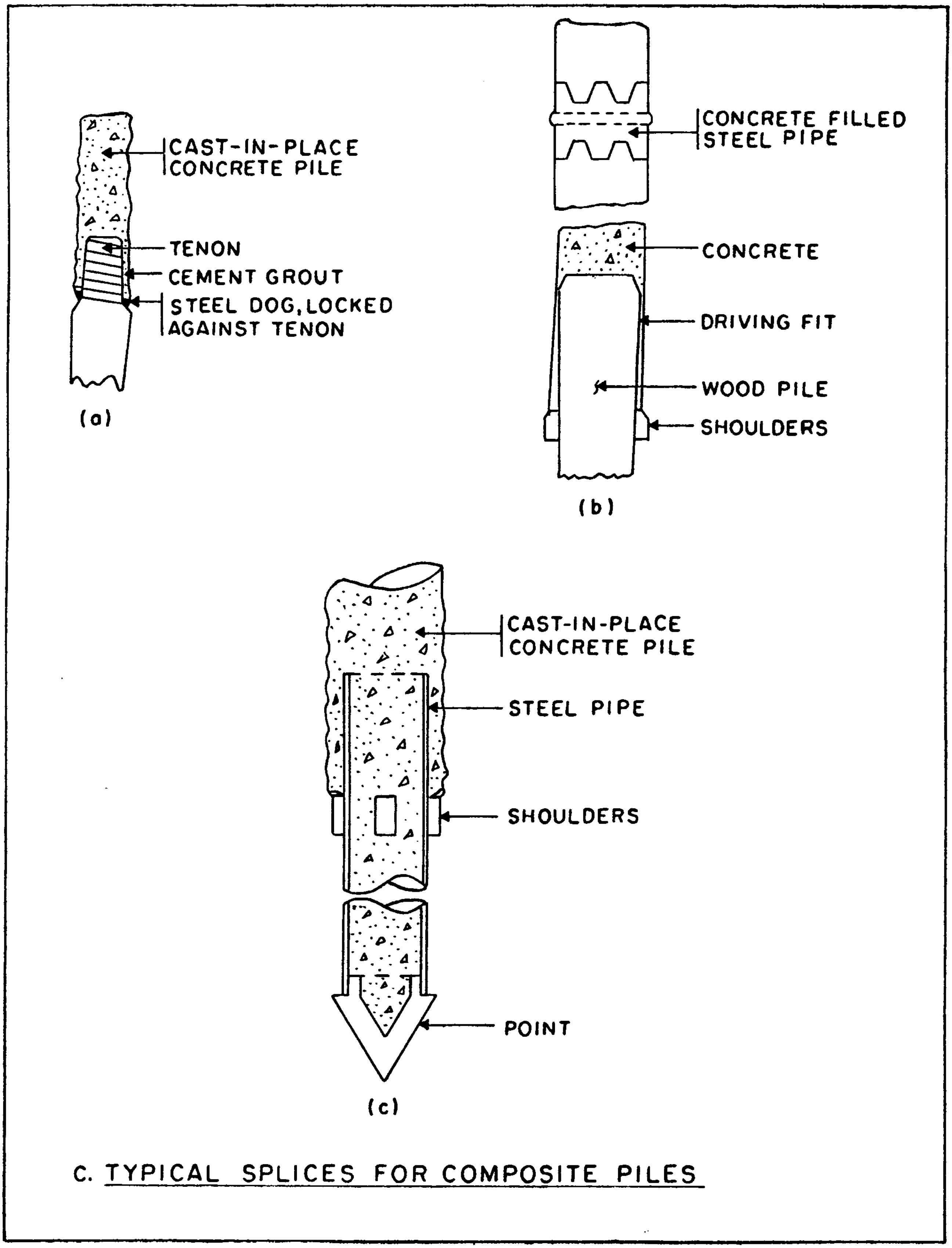


FIGURE 11 (2 of 2)
Typical Splices for Piles

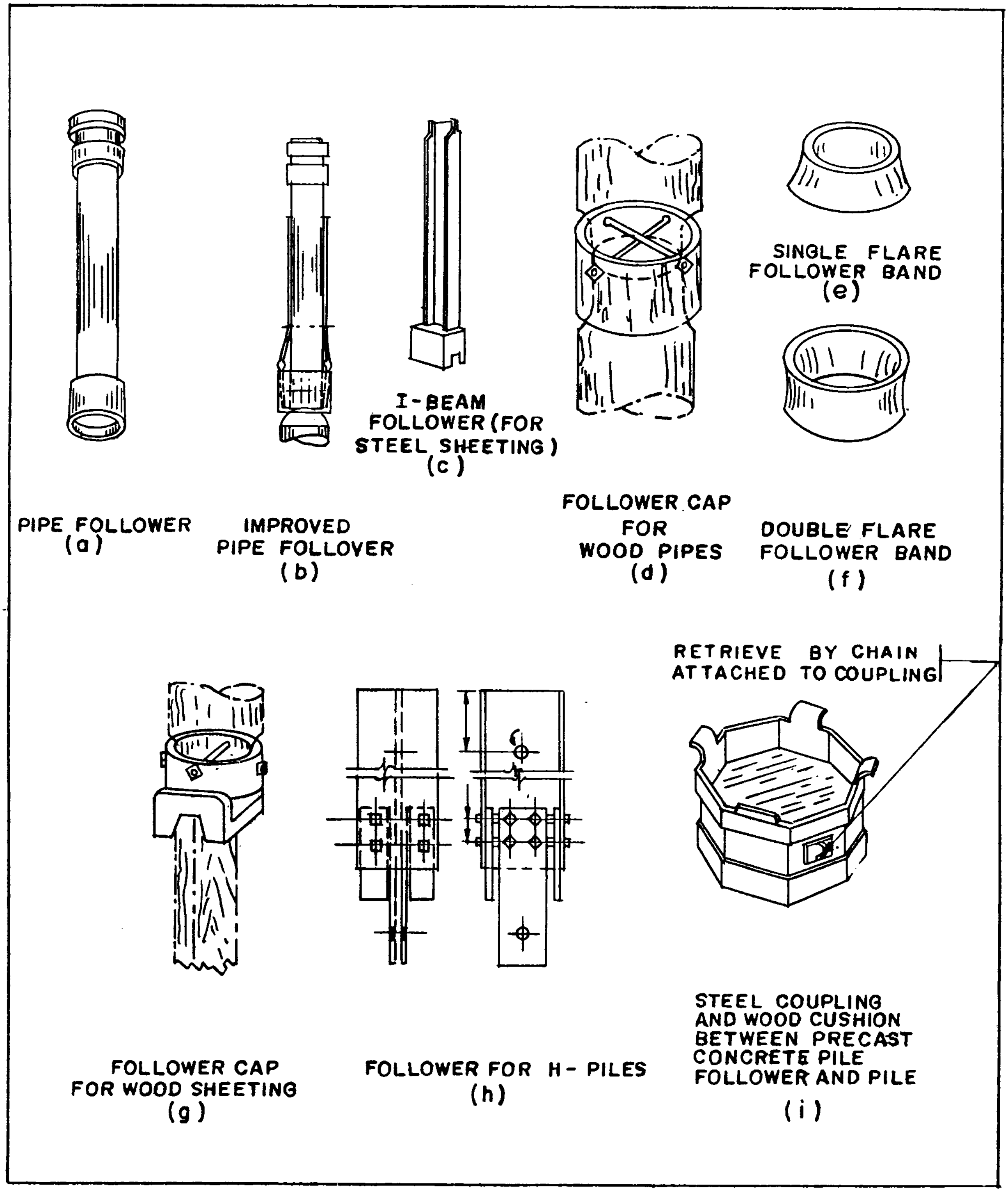


FIGURE 12
Typical Details of Followers

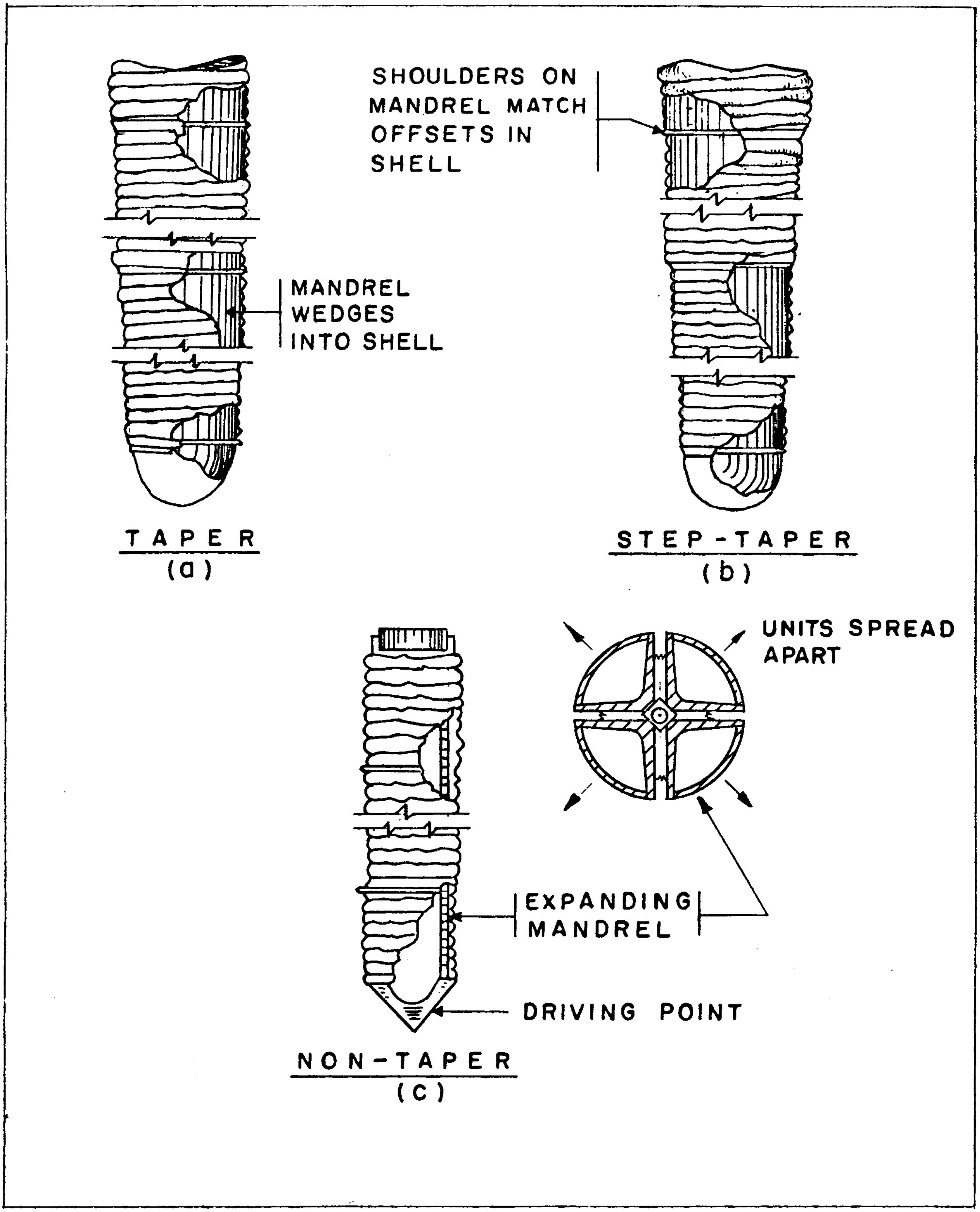


FIGURE 13
Details of Types of Mandrels

g. Devices for Cleaning Interior of Pile. Figure 14 shows types of grabs (or orange-peel buckets) used to remove soil from the interiors of open-end piles after driving. Accumulations of water in driven piles can be removed by use of pump (submersible pump if lift is excessive). Accumulations of water also can be removed by inserting a compressed air or steam line to the bottom of the pile, releasing the air or steam pressure and, in effect, creating a geyser which blows the water out. Soft soil can be removed by similar means. For large diameter or deep piles an air-lift often is used. The air-lift will remove quite large cobbles. For minor accumulations of water, a simple mop is used.

h. Devices for Protecting Dowels or Strands Projecting from Heads of Precast Concrete Piles. See Figure 14.

i. Spuds. A section of heavy pile (usually a heavy-wall pipe) which is driven into the ground to punch a hole through or past obstructions or other source of heavy resistance. The spud is withdrawn, leaving an opening for insertion of the pile.

j. Electric Lighting. Provide electric lighting for pile driving as specified for cranes and derricks; see DM 38.1.

k. Firefighting Equipment. See DM 38.1.

l. Special Equipment for Noise Reduction. Noises arise from two sources, each of which may be suppressed or reduced by different means.

(1) Striking Plates. When driving steel piles, provide canvas hoods to reduce noise.

(2) Exhaust. Provide a muffler or silencer. A large tube fitted with baffle plates may be used.

Section 4. PILE DRIVING BY USE OF VIBRATORY HAMMER

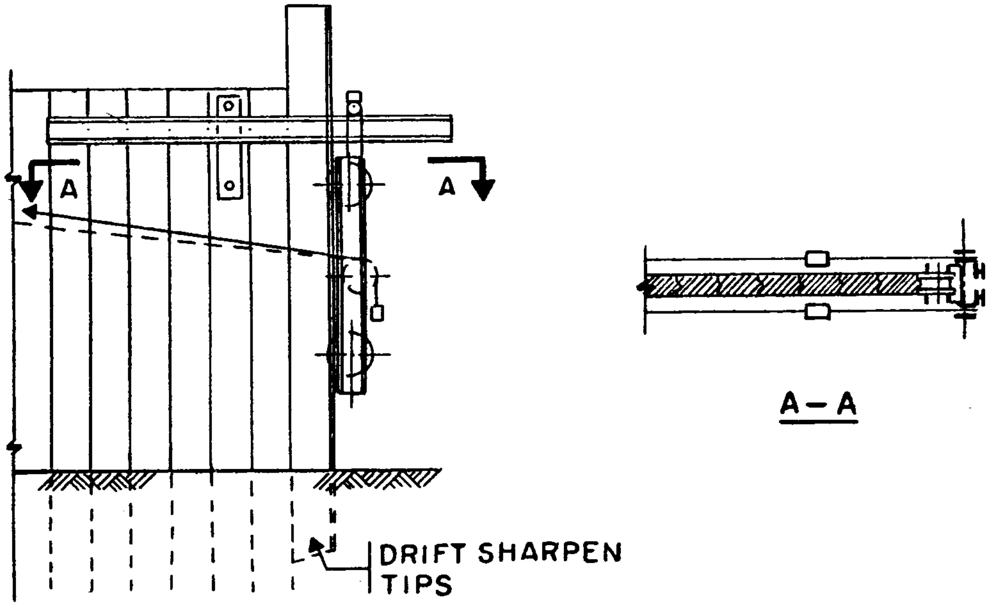
1. TYPES OF VIBRATORY HAMMER. (See Figure 15.)

a. Low Frequency (0 to 1500 cycles/second). This type of vibratory hammer performs better in clay soils and where there is harder driving than do the higher frequency hammers. The reason, in part, is that a variable amplitude of oscillation is attainable and that with higher amplitudes there is a greater "chopping" action which facilitates penetration where point resistance is pronounced. This type of hammer also is applicable in sand soils, although it often does not perform as well as the higher frequency hammer.

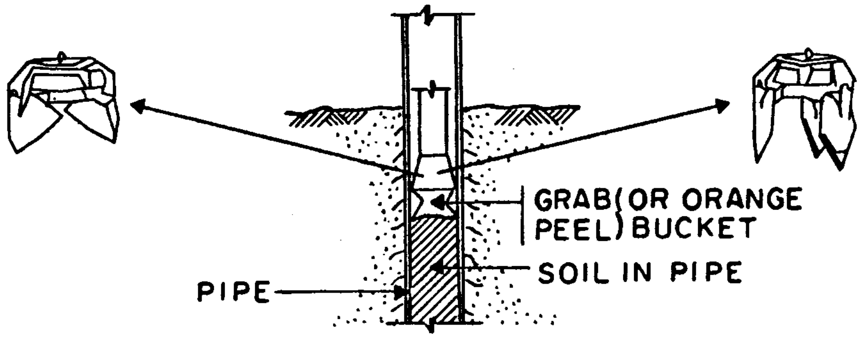
b. High Frequency (1500-1800 cycles/second) vibratory hammer performs best in sand soils.

2. AREAS OF APPLICATION FOR THE VIBRATORY HAMMER.

a. Penetration and Capacity. There is a common misconception that use of a vibratory hammer is not applicable where piles are being driven to a

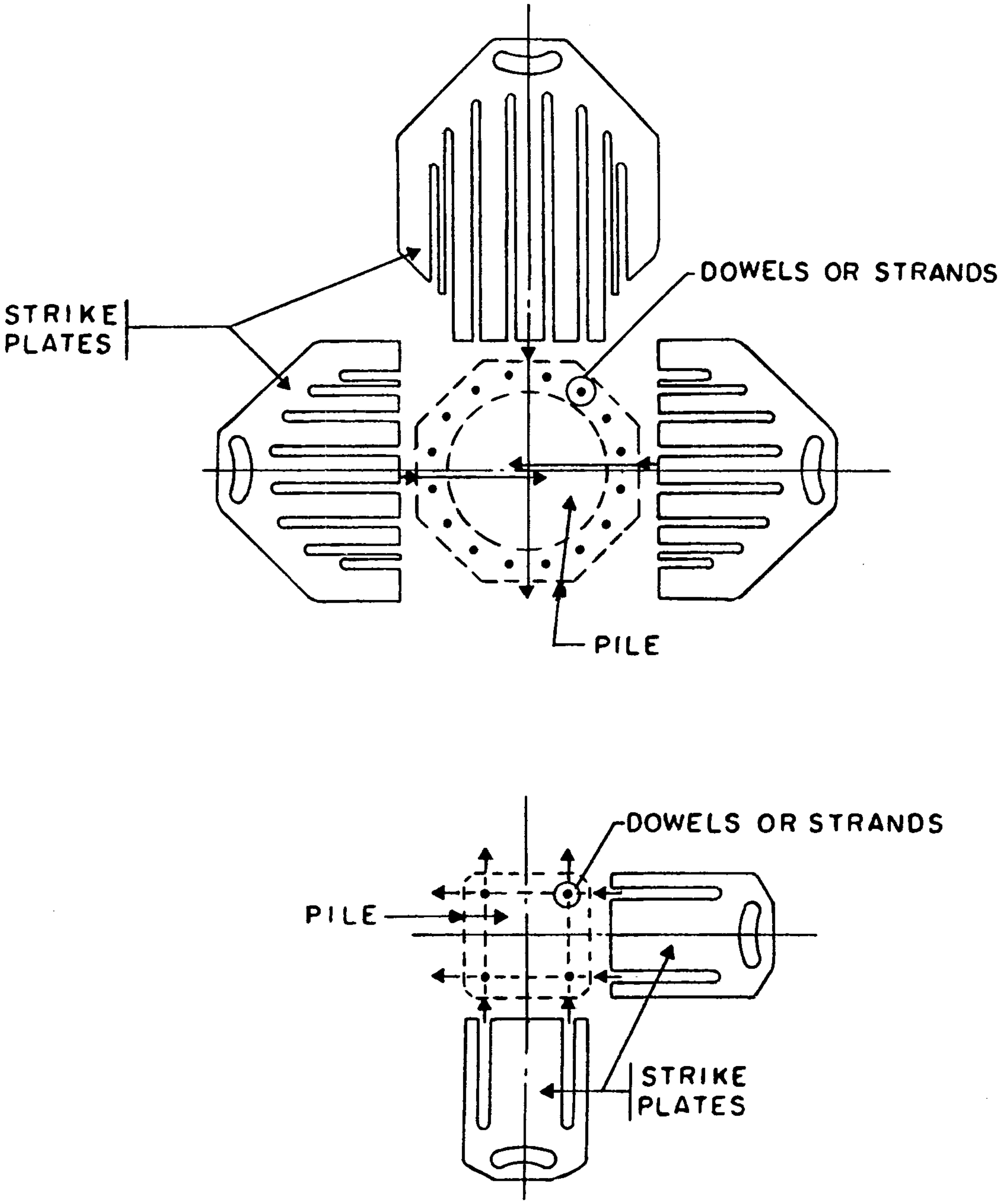


a. DEVICE FOR POSITIONING SHEET PILING



b. DEVICE TO REMOVE SOIL FROM INTERIOR OF PILES INSTALLED OPEN END

FIGURE 14 (1 of 2)
Miscellaneous Accessories for Pile Driving



c. STRIKING PLATES TO PROTECT PROJECTING STRANDS OR DOWELS (PRECAST CONCRETE PILES)

FIGURE 14 (2 of 2)
Miscellaneous Accessories for Pile Driving

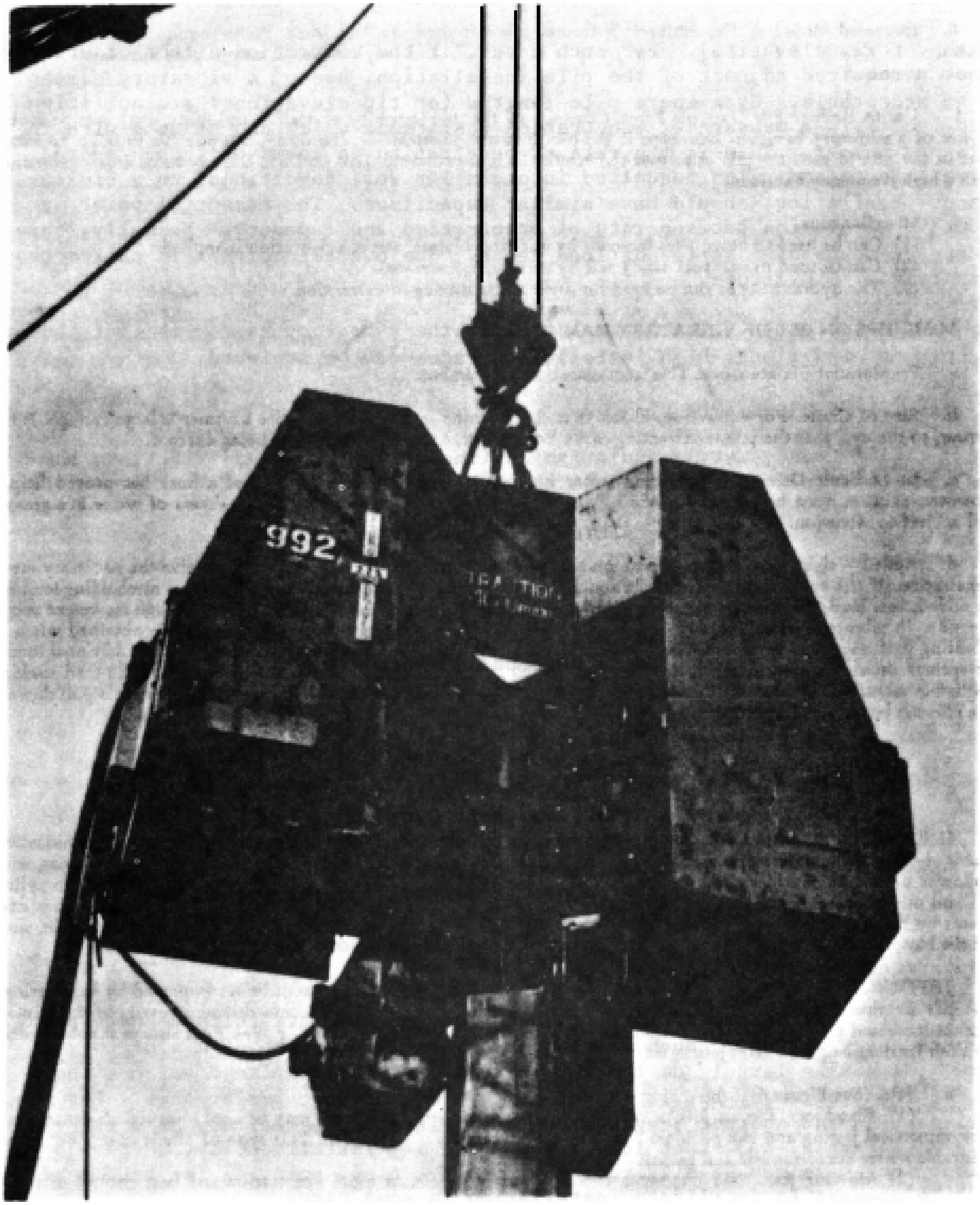


FIGURE 15
Vibratory Hammer

required load-bearing capacity. This misconception results from the fact that engineers are accustomed to determining pile capacity on the basis of penetration resistance--in terms of blows per inch (or per foot) of penetration and there are no "blows" with the vibratory hammer. In some designs, however, resistance is not a good measure of pile capacity and piles are installed to length (or tip elevation). For such cases, if the compaction effect of driving is not a required adjunct of the pile installation, use of a vibratory hammer may be acceptable. Even where pile lengths (or tip elevations) are not stipulated, there is a measure of penetration resistance which can be used with the vibratory hammer. This is the rate of penetration in terms of inches/second or feet/minute and piles installed into similar soil conditions, to a similar rate of penetration, should have similar capacities. The essential point is to derive a relation between rate of penetration and capacity. Normally, this is done by means of a series of load tests. The overall aproach is called the "Principle of Similitude."

b. Installation. The general use for the vibratory hammer is that, under the correct conditions, high installation rates can be achieved.

c. Influence of Type of Soil.

(1) Loose, wet, granular soils (including gravels): Vibratory hammers show their best performance in this type of soil.

(2) Soft and "not-so-sticky" clays: Vibratory hammers generally work well.

(3) "Sticky" clays, hardpan, decomposed rock: Vibratory hammers show their poorest performance in these types of soil because of their limited "chopping" effect (as compared to an impact hammer). If use of a vibratory hammer is desired in such soils, try one of the heavier models with a large amplitude of oscillation.

d. Influence of Type of Pile.

(1) Nondisplacement piles (H Beam, Open-End Pipe, Steel Sheet Piling): Vibratory hammers show their best performance with these types of pile. They have a record of particularly good performance when used to install large diameter caissons (up to 15 feet diameter) and, in general, open end pipes of sufficient size that a plug does not build up in the end of the pile. Use of vibratory hammers (sometimes in pairs) to sink caissons has been a particularly successful application.

(2) Displacement piles (Timber, Precast Concrete, Closed-End Pipe, Concrete Sheet Piling): Such piles can be installed by use of a vibratory hammer (depending largely on the size--the larger the displaced volume, the greater the problems), but it is not their arena of best performance. For smaller piles and shorter lengths, use of a vibratory hammer may be worth a try. For example, a 30-foot long timber pile may install easily, whereas a 60-foot long pile may be difficult to install. Also, pointing the bottom of the pile appears to facilitate installation in some cases.

e. Use As an Extractor. One of the best applications for the vibratory hammer.

f. Use to Limit Noise. In general, the vibratory hammer is much less noisy than impact hammer. The principal source of noise is the generator which can be muffled.

g. Use As a Probe. The vibratory hammer, with its facility for extraction without uncoupling from the pile, can be used to probe for obstructions.

h. Increased Mobility. The vibratory hammer often is used without leads. Power equipment is limited to a generator. In general, the total equipment setup is of less bulk and weight than for comparable installation by use of impact hammer.

i. Use to Reduce Pile Damage. Impact damage to the pile (crushing of head or tip, splits, etc.) may be avoided by use of a vibratory hammer. However, if the pile does not penetrate continuously, it is possible to build up enough heat in the pile to melt the pile or to fuse the interlocks in sheet piling. This problem is likely to be more pronounced with a high frequency hammer.

j. Miscellaneous.

(1) Can be used to move piles laterally by exerting a lateral strain as vibration is applied.

(2) Can be used to compact sandy soil by successive insertions.

(3) The hydraulic type can be used for underwater driving or extraction.

3. SOME TIPS ON USE OF VIBRATORY HAMMERS.

a. Size of Crane. For extraction, check that the machine (crane) handling the hammer is large enough. It may appear, to the eye, that the pile is extracting easily but, in fact, a considerable pull is being exerted.

b. In Difficult Driving. Introducing water into soil around the pile by use of a hose has proved helpful. However, caution must be exercised since a "quick" condition can be generated by an excess of water in a granular soil subject to vibration.

c. Added Weight. The external force on the vibrating system must be great enough to give the necessary rate of penetration. If the total weight of the pile and vibrator (i.e., the external force) is inadequate, a surcharging load may be added, this load being supported on springs so that it is not part of the vibrating body, although its weight acts on the pile. In vibrators which employ additional loads supported on springs, the best results are obtained when the vibrating part weighs as little and the added load as much as possible. The natural frequency of the additional load on its springs should be considerably lower than the frequency of the vibrator. In these conditions the load itself has negligible vibration. If instead of a surcharging load a rope is attached to the platform of the vibrator, a pull-down on the pile can be obtained by making use of the weight of the piling rig or crane to provide the reaction.

Section 5. PILE INSTALLATION BY VARIOUS DEVICES

1. UNDERWATER DRIVING. Commercial hammers which can be used for underwater driving are indicated in Table 4. Such hammers are available for use in depths of water up to 200 feet. The alternative of driving with a follower should be considered whenever underwater driving is contemplated. When driving underwater, use cylinder oil and other accessories as specified by the manufacturer for such purpose. Also, calculate the buoyant effect of the water on the submerged hammer and provide an equivalent deadweight on the hammer casing; otherwise, the energy of the blow will be reduced. Alternatively, increase the required driving resistance for hammer selection.

2. JETTING. Piles may be "sunk" into place by jetting which may, or may not, be accompanied by hammering on the pile or alternately raising and dropping the pile. Jetting also is used to relieve driving stresses, to save time, to obtain increased penetration of piles, and to decrease vibration incident to driving piles. Piles always should be driven to their final embedment after jetting has ceased.

a. Jets. (See Figure 16.)

(1) Fixed jets. Precast jets in concrete piles and concrete sheet piles may be used to avoid off-center and/or unsymmetrical jetting and the problem of keeping plumbness and alignment. This type of pile is costly but may be desirable where conditions do not permit using a loose pipe jet.

(2) Movable jets. Two jets symmetrically located give most rapid penetration and best control of the pile path.

b. Jet Pipes. Diameters (up to 4 inches) should be selected to meet the conditions in the field. Nozzle diameters should be from 3/4 to 1-1/2 inches.

c. Hose. Hose should be approximately 1/2 inch greater in diameter than the jet pipe and should have a protective jacket of canvas, cotton, or steel wires. Hose length should be as short as possible to minimize friction losses.

d. Pumps. Provide bronze fitted pumps exclusively.

(1) Capacity and pressures. Provide for pressure of 100 to 200 p.s.i. generally; 100 to 150 p.s.i. for gravel, and 40 to 60 p.s.i. for sand. Selection of capacity and pressure must provide a volume of water large enough to allow discharged water to rise along the sides of the pile for the full jetting depth.

(2) Design data. See Tables 7, 8 and 9 for data regarding pump sizes, discharges, and pressure losses in jet pipes and hoses.

e. Methods.

(1) Water Jetting. This is a method designed to discharge a water jet at the pile tip, with both volume of water and pressure sufficient to allow the discharge to come up around the pile.

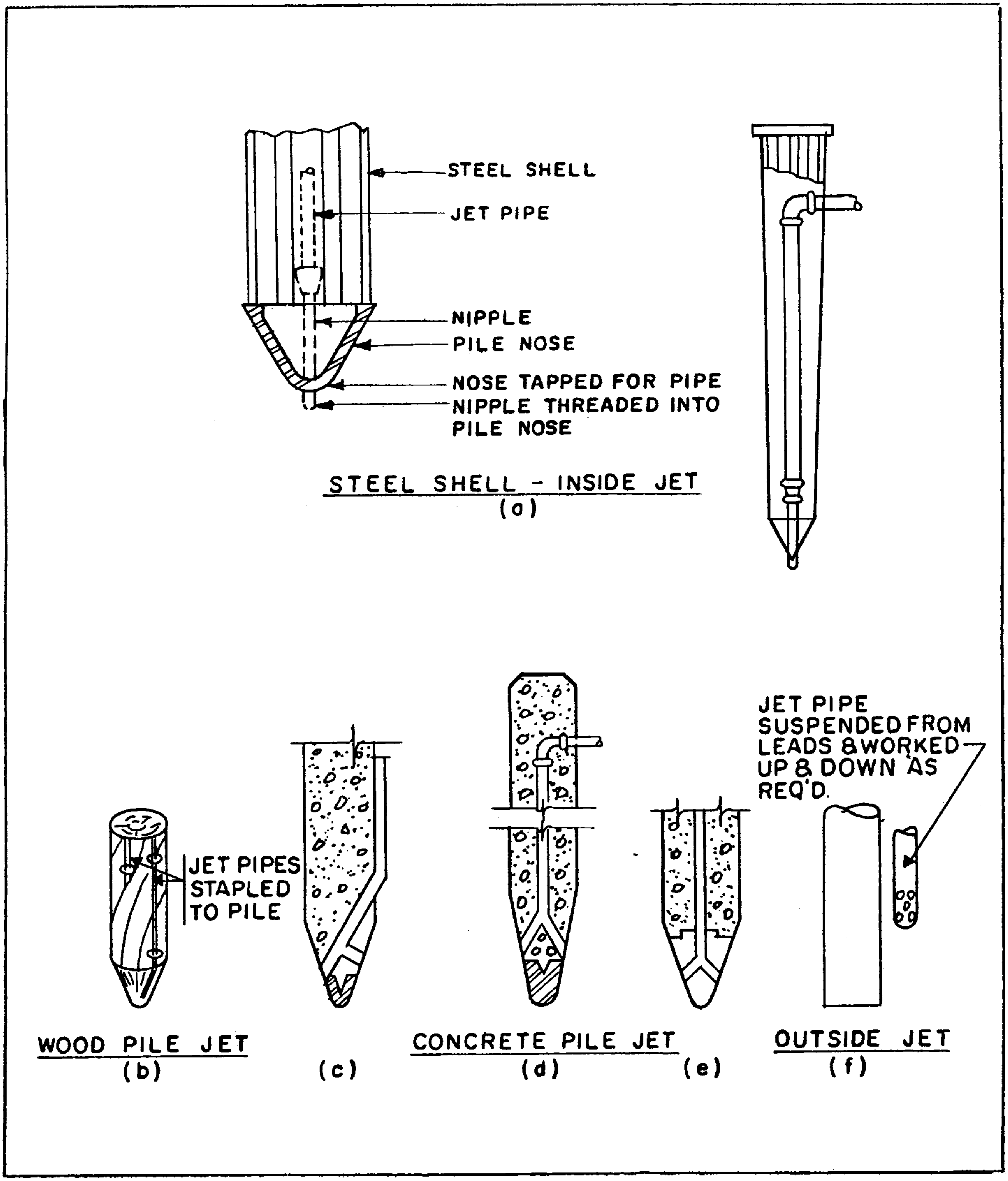


FIGURE 16
Typical Jetting Arrangements

TABLE 7
Size of Pumps Needed to Secure a Specified Discharge

g.p.m.	Steam Pressure (p.s.i.)	Discharge Pressure (p.s.i.)	Diam. of Steam Cylinder (in.)	Diam. of Water Cylinder (in.)	Stroke (in.)	Boiler hp. Required
175[1]........	100	175	10	6	10	45
225[2]........	100	200	10	7	10	60
345[3]........	100	175	12	8-1/2	12	90
500.........	100	175	14	8-1/2	15	145
800.........	100	175	17	10-1/4	15	200
1,000.......	100	175	20	12	12	250
500.........	100	175	12 + 18	8-1/2	12	100
800.........	100	175	14 + 20	10-1/4	15	140
1,000.......	100	175	16 + 25	12	18	175

[1]Duplex-packed piston pattern pump.
[2]Duplex-center-packed plunger pump, single steam end.
[3]Duplex-center-packed plunger pump, compound steam end.

TABLE 8
Approximate Discharge in Gallons Per Minute from Nozzles
Attached to 50 ft. of 2 1/2 in. Pipe or Hose

Pressure at pump (p.s.i.)	Size of Nozzle opening (in.)				
	3/4	1	1-1/4	1-3/8	1-1/2
100	160	275	400	460	515
150.............................	195	340	495	570	640
200.............................	220	395	580	670	740

(2) Spade or Multiple Jetting. This is a method for assisting the driving of sheet piling.

(3) Combined Air and Water Jetting. This method is useful when a double water jet and heavy driving cannot secure the desired penetration.

(4) Air Jetting. This method is practical for shallow depths, for probing or friction reduction, but not for deep penetrations.

TABLE 9
Loss of Pressure by Friction in Jet Pipe and Hose

Size of Pipe (in.)	Friction Loss, lb. per ft. of Length								
	100 (g.p.m.)	150 (g.p.m.)	200 (g.p.m.)	250 (g.p.m.)	300 (g.p.m.)	350 (g.p.m.)	400 (g.p.m.)	450 (g.p.m.)	500 (g.p.m.)
2	0.14	0.30	0.55	0.85	1.20	....	....	....	....
2-1/2	0.05	0.10	0.18	0.28	0.40	0.54	0.72	0.90	1.12
3	0.02	0.04	0.07	0.12	0.16	0.22	0.30	0.40	0.45
3-1/2	....	0.02	0.03	0.05	0.08	0.10	0.13	0.16	0.20
4	....	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.11
5	....	....	....	....	0.01	0.02	0.02	0.03	0.04
6	....	....	....	....	....	....	....	0.01	0.02

f. Limitations. Jetting applications are limited:

(1) In clay soils where plugging of the jets may occur.

(2) In cohesive soils where jetting is not useful or practical.

(3) In fine grained, poorly draining soils where jetting may loosen the soil around piles already driven.

(4) In locations where there is considerable ground water and the material disturbed by the jets cannot escape.

3. PREBORING, JACKING, SCREWING, AND PULL-DOWN METHODS. See Section 1 for descriptions. These methods of pile installation are used where soil conditions are such that the use of displacement piles is unsatisfactory (soils subject to heave) or where the vibrations or noise incident to pile driving must be avoided, or where overhead clearances are a problem.

4. SPECIAL CONSIDERATIONS RELATIVE TO INSTALLING PILES IN PERMAFROST AREAS.

a. General. Frozen soil is a material with considerable, often rock-like, strength. Unless steel "H" sections are used, installation of piles by conventional means (i.e., impact driving) often is impossible without excessive breakage, and resort is made to:

(1) Dropping the pile section into a dry augered hole or a hole opened by use of a rotary or churn drill and backfilling the hole with a soil-water slurry which, upon freezing, bonds to the pile.

(2) Steaming a thawed shaft into the ground; pressing or driving the pile into the thawed material, and allowing the thawed material to refreeze.

Piles in permafrost are not driven to resistance, but to specified penetration or tip elevation which is determined by the design engineer. The responsibilities of the persons installing the piles are:

(1) To obtain the necessary penetration.

(2) To use methods that will permit the soil around the pile to refreeze, quickly. The pile capacity (both resistance to downward loads and resistance to frost heave) depends on support from the surrounding soil which, in turn, requires that the soil adhere (adfreeze) to the pile. Until this adfreeze develops, only a fraction of the pile capacity is developed.

(3) To minimize disturbance to the permafrost, the ground cover, and the site in general. Any disturbance will upset the heat balance in the ground possibly causing (unless remedial measures are taken) thaw and refreezing with consequent settlement, followed by heave, which will affect buildings, pavements, and utilities. It may take years for the heat balance to be restored.

b. Site Preparation.

(1) If possible, restrict movement of pile placing equipment to perimeter of building so that the disturbed area will be accessible for the execution of remedial measures (placing of additional organic fill, for example).

(2) In the usual construction season, disturbance of the ground surface is likely to result in increased depth of thaw, which turns the site into a quagmire, making work difficult. Consider covering the area to be worked with a blanket of gravel or broken stone and working on top of the blanket.

c. Equipment.

(1) Steam jetting. Generally 3/4 inch to 1-1/4 inch pipe, open or slightly crimped at point to give better jetting action. In gravelly ground, chisel bit may facilitate penetration. Higher steam pressures (100-120 p.s.i.) are desirable. In "dry" soils, consider adding water to the hole during steaming to promote thawing. If the jet only opens a narrow hole, consider working jets alongside pile as pile is advanced.

(2) Augering or drilling. Truck mounted augers usually applicable in silts, clays, and some sands. In coarse sands and in soils containing cobbles, rotary or churn drilling or local prethawing may be required.

d. Cautions.

(1) In steam jetting method, carefully limit volume of thawed zone in order to minimize time for refreezing.

(2) In steam jetting or dry auger methods, slurry should be placed into hole at as near freezing temperature as feasible in order to minimize time for refreezing.

(3) In steam jetting or dry auger methods, seat pile firmly on bottom of hole to obtain partial capacity to support partial weight of construction while waiting for adfreeze to develop.

Section 6. SOME GUIDES FOR THE PILE DRIVING FOREMAN AND INSPECTOR

1. INTRODUCTION. This section deals with important considerations that are under the control of field personnel when installing piling with an impact hammer, to achieve a desired capacity to resist downward axial loads. There are many considerations that are controlled by the designer, such as the type and size of pile, penetration requirements, pile spacing, and tolerances on location, all of which are prescribed before the work begins. These are not considered here. There also are cases where the capacity of piling to resist uplift or lateral loads is important. These cases, too, are not considered here.

In general terms, a pile driving operation must be evaluated in terms of overall performance, i.e., how much of the blow of the hammer is transferred into usable work in moving the tip of the pile. To this end, paragraphs 3 to 8 must be considered.

Also, the loss of energy into those ground strata that are not expected to contribute to the support of the pile (generally, the strata above the bearing stratum) should not be included in evaluation of the penetration resistance achieved. To this end, paragraphs 9 to 15 must be considered.

2. SOME PRELIMINARY MATTERS.

a. Job Specifications. Specifications must be read and understood. Are piles to be driven to resistance only, or is a specified bearing stratum to be reached? Is a minimum penetration (tip elevation or penetration into bearing stratum) required? What alternatives are permitted? What is the intended function of the piles (resistance to downward load; resistance to lateral load, resistance to uplift, compaction of soil, etc.)? Job specifications should present this information.

b. Preparation of Site. Coordinate with the excavator who should be persuaded (or compelled) to prepare the site for efficient movement of the pile rig, for access and egress, for delivery of materials, and for their storage. Has dewatering been provided? Will the braces for the excavation be in the way? If so, what provision has been made for their removal?

c. Coordination With Other Trades. Pile installation is dependent on preparatory work by the excavator. Similarly, the concrete work and other trades are dependent on completion of installation of piling and must be coordinated with full consideration of the needs of all parties. Proper scheduling of delivery of materials and equipment is essential to ensure continuity of operations, once the work is started.

3. CONDITION OF HAMMER AND POWER EQUIPMENT.

It will be apparent that the driving equipment must be in good condition if the hammer blow is to be properly delivered to the pile. For example, the hoses must not be kinked or crimped, valves should be fully opened, the hammer must not bind in the leads, and the cap should bear fully on the head of the pile, which should be trimmed to fit.

To check the output of the hammer, the following items may be observed:

a. Steam or Air Hammer. The gauges at the power source are the basic check. Determine that there are no leakages between the power source and the ram, that line sizes are ample to preclude excessive losses, and that line lengths are not excessive. These factors are reflected in the proper ram rise which should be checked. The instance of getting so much ram rise that the ram strikes the top yoke should be avoided, not only because of possible damage to the hammer, but because there is a tendency to lift the hammer off the pile.

b. Diesel Hammer.

(1) Check the fuel. A fuel with a lower BTU content will decrease the energy output. Check the fuel used against the manufacturer's recommendations.

(2) Check the fuel input by checking the pump setting against the manufacturer's standard.

(3) Unsteady hammer operation should be a signal to check the fuel pump and related components and to check for vapor lock.

(4) Observe the exhaust for indications of water in the fuel.

(5) Check the compression ratio. In the open-top diesel, the time required for the piston to stop bouncing on the cylinder's air cushion is an indicator. In the closed-top diesel, check the gauge on the upper chamber bounce.

4. SPEED OF HAMMER. For impact hammers, all other things being equal, the energy delivered is a function of the speed of the hammer. In general the faster the succession of blows the more energy delivered to the pile, and hence the greater the capacity for a given indicated set. The hammer speed must be checked during driving by a timed count of blows. The manufacturer's rated speed should be adhered to.

5. CUSHION OR CAP BLOCK. The hammer blow usually is delivered to the pile through a cushion or cap block. This block absorbs part of the energy of the impact and reduces that part which is delivered to the pile.

The cap block must be kept in good condition, although readings of penetration resistance should not be made immediately after a new block or cushion is installed or until the new material has had an opportunity to be properly set. It must be of reasonably firm materials and must be replaced when crushed. As a rule of thumb, some practitioners inspect the cushion material every 1000 blows, replacing it if excessively compressed or excessively disrupted. Unless these things are tended to, the recorded sets will be too low, often drastically so. Special care should be taken that foreign energy-absorbent materials (wood chips, pieces of rubber, etc.) are not used in the cap-block recess.

6. FOLLOWERS. When a follower is used, the apparent sets will be too low. There are two reasons: (1) the effective weight of the pile is increased and

(2) if the follower does not fit tight, there is an energy loss due to "chatter" and to separation between pile and follower under the impact wave.

The effect of the weight of the follower can be considered by use of the Hiley (or similar formulas). The remedy for relative movement or chatter is to provide the follower in a single-length section, stiff enough to prevent whip during driving and to insist that the follower fit tightly to the pile.

Followers should be of steel, hardwood, or similar material which will minimize absorption and cushioning of the hammer blow in the follower.

7. DISTORTION OF THE PILE AXIS. Distortion of the pile axis (Figure 17) commonly is observed. It is caused by the presence of obstructions in the soil, variations in soil density, eccentric blow of the hammer, skewing the leads, or other factors that tend to cause the pile to walk off-line. Distortion of the pile axis is detrimental to the capacity of the pile because:

(1) bending stresses are introduced into the pile;

(2) the effectiveness of the hammer blow is reduced because energy is used up in "whip" of the pile.

Care should be taken to minimize the occurrence of distortion of the pile axis as, for example, not using excessive force to hold the pile head in position. Frequently, as the pile is being driven, it will tend to drift off location and/or plumb or batter. When only a short length of pile is in the ground it is usual to guide the pile back into desired alignment by raising or lowering the boom, by travelling against the pile, or by use of the spotter. Once substantial penetration has been made, however, such attempts are likely to be more illusory than effective and the detriments in terms of broken piles and/or locked-in stresses exceed the benefits. When this occurs, consideration should be given to "following" the pile down, i.e., to allow it to seek its own course into the ground. There is substantive evidence that, within broad limits, the fact of the embedded portion of a pile being out-of-plumb has little effect on its strength or capacity.

In cast-in-place, pipe, or caisson piles, the deviation of the pile axis from a straight line should be checked against the specified tolerance (usually that a portion of the tip of the pile can be seen). If distortion is suspected, the penetration resistance should be increased, say, 10% to 20% to compensate the loss of hammer blow energy due to "whip" of the pile.

8. DAMAGE DURING DRIVING. Some examples of damage to piling due to driving are shown on Figures 18 and 19. Prevention consists in not overdriving the pile. This may, however, be at variance with the requirements for minimum penetration or for the development of a specified penetration resistance. Accordingly, the problems of damage to piling during driving often becomes a matter of determining how hard one can drive the pile without damage. This, in turn, becomes a problem of detecting damage when it does occur. Indicators of possible damage to a pile during driving include:

(1) A sudden decrease in penetration resistance indicating breakage of the pile.

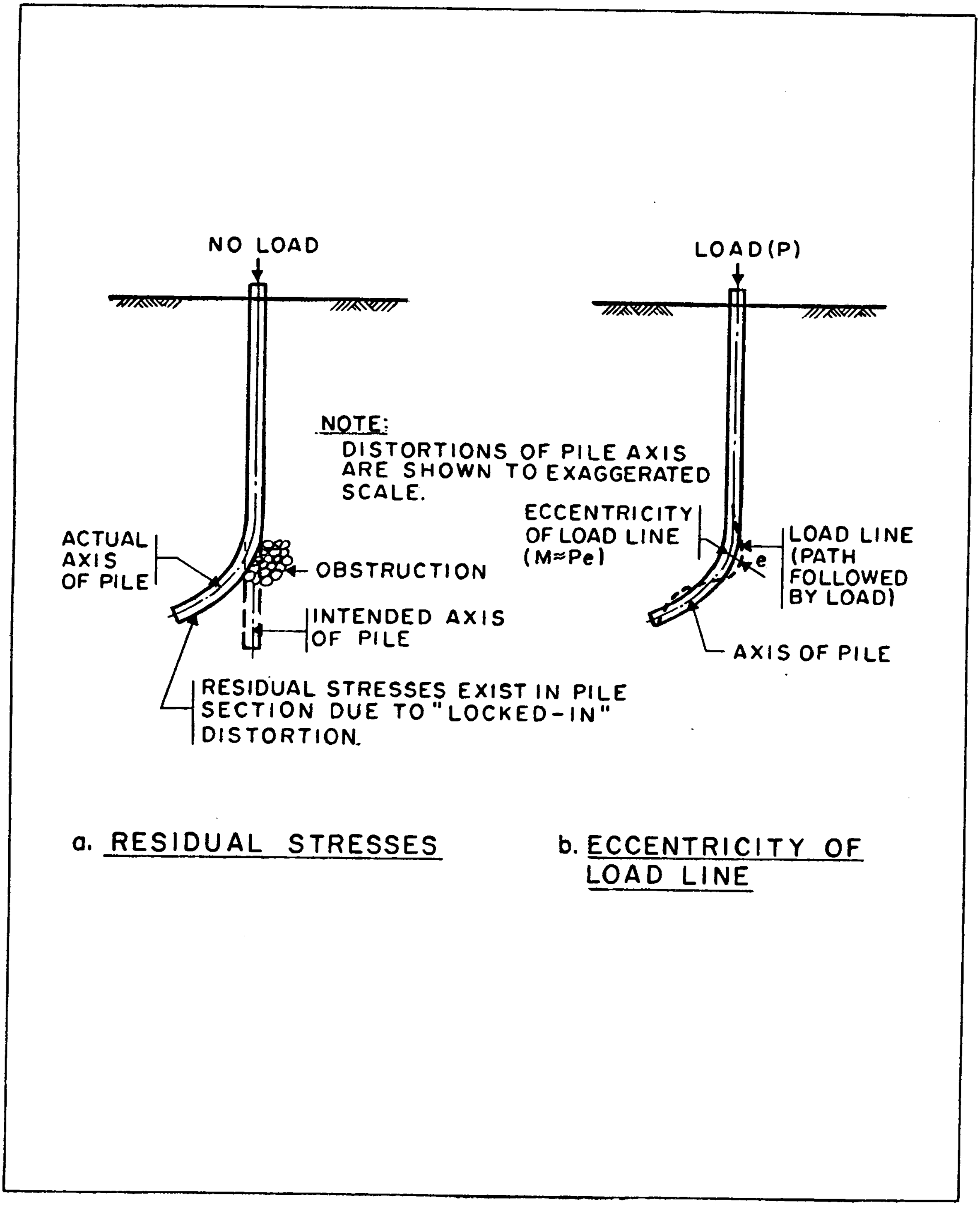
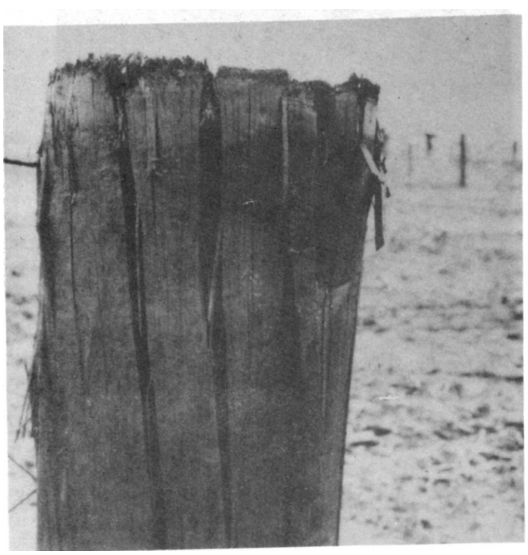
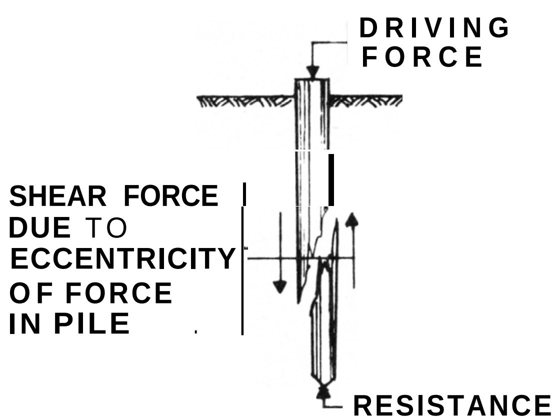


FIGURE 17
Effects of Distortion of Pile Caps

a. **CRUSHING OF TIPS OF TIMBER PILES DUE TO OVERDRIVING**



b. DAMAGE TO **BUTT OF TIMBER PILE DUE** TO **HARD DRIVING**



c. DIAGRAMMATIC REPRESENTATION OF BROKEN TIMBER **PILE**

FIGURE 18
Damage to Piling Due to Driving

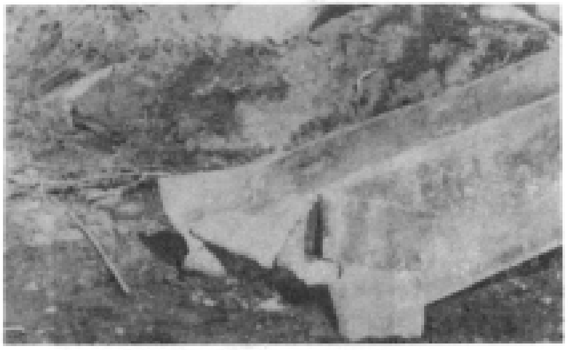


FIGURE 19
Damage to Steel "H" Piles Due to Overdriving

(2) Sudden, lateral "snap" of the head of the pile, indicating breakage due to bending.

(3) Damage to the head of the pile, possibly reflecting similar damage to the tip.

(4) Two, or more, cycles of alternating decrease and increase in penetration resistance, indicating progressive crushing of the tip.

(5) Periodic vibration of piles previously driven, indicative of interference with pile currently being driven.

(6) Crushing or distortion of the pile as indicated by internal inspection of cast-in-place pipe, or caisson piles prior to concreting.

(7) Driving resistance suddenly increases or becomes irregular, whereas the soil formation cannot account for it, indicating breakage.

(8) The pile suddenly begins to move, laterally.

Care also must be observed in filling cast-in-place concrete or pipe piles to assure that there are no voids. To this end a 6-inch, or greater, slump normally is used.

9. SUSTAINED DRIVING RESISTANCE. For piles installed by impact hammer, the capacity normally is measured by the resistance to penetration, expressed in terms of the number of blows per foot of penetration or per inch of penetration. It is common to assume that the two measures (per foot or per inch) have the same significance. For example, it is commonly assumed that a pile has the same capacity whether driven to 60 blows per foot, or 5 blows per inch, or 1 blow per 1/5 inch and such a pile often will be stopped, in order to reduce the chances of damaging the pile, as soon as the resistance mounts to 5 blows for a one-inch distance. However, this assumption is not correct. In practice, the pile driven to 60 blows per foot usually will perform better, i.e., it will settle less under the same applied load, than the one driven to 5 blows per inch. The reason is that pile capacity largely is a function of the amount of energy expended on installing the pile and not just of the final resistance. Therefore, within the limitation that the pile not be driven so hard that it is damaged, a sustained driving resistance for, say, one foot, is advisable.

10. EXCESSIVE VARIATION IN PILE LENGTH. It is often observed that the lengths of the piles in a footing are not all the same. This is due to several factors. The soil is not uniform. The soil is progressively compacted as successive piles are installed. The level of the bearing stratum varies. Where large (more than, say, 5 to 10 feet) variations in length occur, the adequacy of the group should be questioned. If feasible, the matter should be brought to the attention of the designer. If not feasible, the matter may be judged, in a rough way, by reference to the Equivalent Footing Analogy. (See Figure 20.)

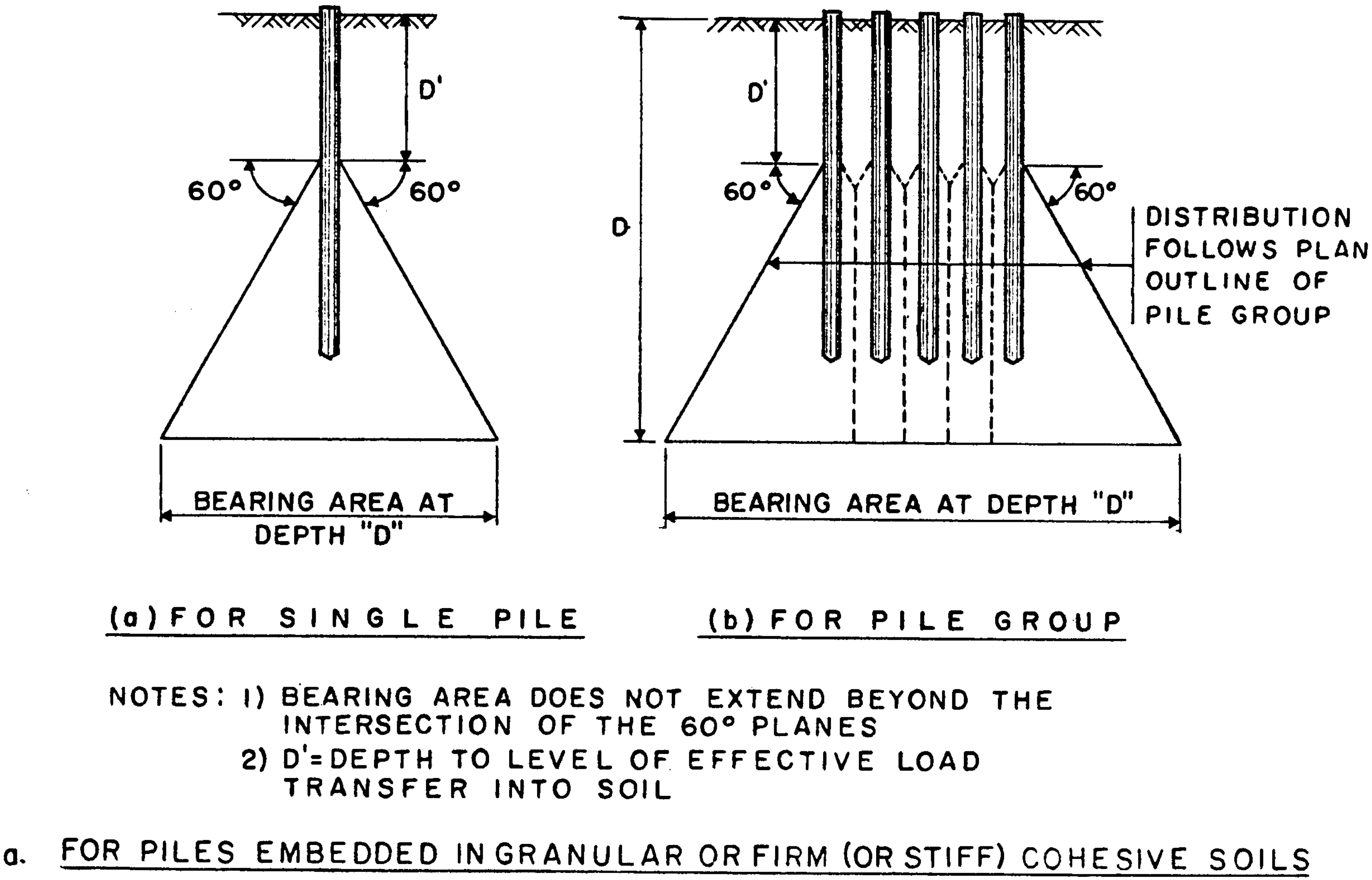
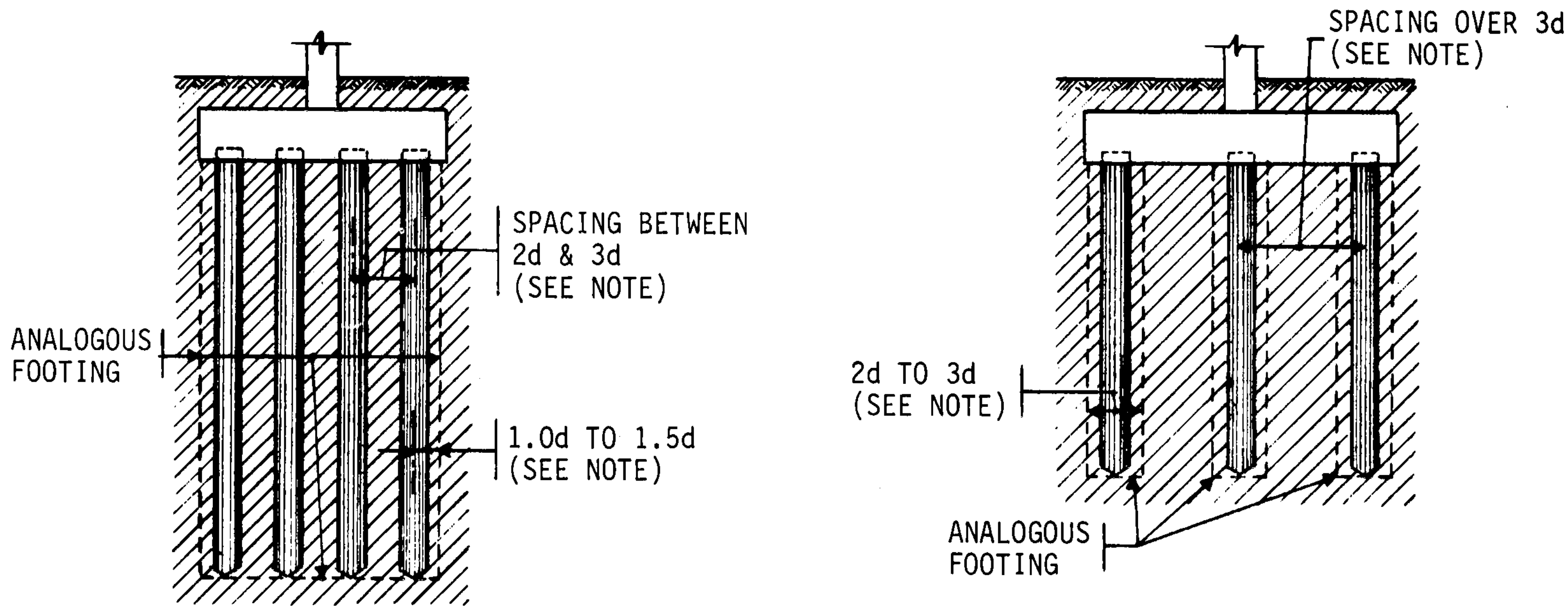


FIGURE 20 (1 of 2)
The Equivalent Footing Analogy



(a) CLOSELY SPACED PILES

(b) PILES SPACED FAR APART

NOTE: d = DIAMETER OF PILE

b FOR PILES EMBEDDED IN SOFT OR LOOSE, COHESIVE SOILS

FIGURE 20 (2 of 2)
The Equivalent Footing Analogy

11. MINIMUM ENERGY OF HAMMER. It will be apparent that it makes no sense to try to drive a spike with a tack hammer. The same thing applies to driving piles. Unless the hammer is heavy enough, a pile can have a very low apparent set but without attaining any significant penetration or capacity. This is the reason for the provisions relating to minimum energy in Tables 1 and 2.

12. WHERE DRIVING IS INTERRUPTED. For piles in cohesive (or mixed) soils, if driving is interrupted, there is a tendency for the pile to set-up or freeze; i.e., upon the resumption of driving the set will be much less than that recorded before the interruption. Under such circumstances, the assumed correlation between capacity and penetration resistance is not meaningful, and the pile must be driven a sufficient distance to break the freeze, before readings of penetration resistance can be interpreted. The distance may be a few inches or several feet. A value of 5 feet commonly is used.

13. JETTING. The use of jetting sometimes is required in order to obtain sufficient penetration to get the piles to bear in satisfactory material below compressible strata that may underly the site.

The jetting operation disturbs the soil around and below the pile (this being its function), and readings of penetration resistance should not be taken while jetting is in progress or until the pile has been reseated after jetting has been completed.

14. SEQUENCE OF INSTALLATION AND TOO-CLOSE SPACING. As the piles for a group are driven, the surrounding and underlying soil is compacted, both by the volumetric displacement of the piles and by the vibrations incident to driving. As a result, the ground tightens up, and the last piles driven tend to run shorter, for a given penetration resistance requirement, than the first piles installed. This is particularly true when the piles are "boxed in" by driving; i.e., the perimeter piles in the group are driven first and the center piles then are filled in, or when the pile spacing is too small so that succeeding piles must be driven through progressively more compact soil. These procedures should be avoided. Excessive variations in length should be investigated, as described in paragraph 10.

15. HEAVED PILES. Another possible detrimental consequence of improper sequence of installation and/or too-close spacing of piles is that the piles installed first in the sequence may be heaved by the ground displacements resulting from installation of the subsequent piling. In addition, the lateral pressures developed in the soil may displace (or break) adjacent piles or damage nearby buildings or utilities.

Most engineers consider that heave is detrimental to pile capacity and that the heaved piles will settle under load by an amount approximately equal to the original heave plus the normal settlement otherwise anticipated. Accordingly, it is concluded that heaved piles must be redriven to bearing, although a nominal amount of heave (say, 1/4 inch) generally is considered to be acceptable without bothering to redrive.

Heave is not necessarily detrimental, however, depending on circumstances. Cases of heave should be referred to the design engineer for evaluation.

REFERENCES

NAVFACENGCOM Design Manuals and P-Publications

DM-7	Soil Mechanics, Foundations and Earth Structures
DM-25	Waterfront Operational Facilities
DM-38	Weight Handling Equipment and Service Craft

Government agencies may obtain Design Manuals and P-Publications from the U. S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. TWX: 710-670-1685, AUTOVON: 442-3321. The stock number is necessary for ordering these documents and should be requested from the NAVFACENGCOM Division in your area.

Non-Government organizations may obtain Design Manuals and P-Publications from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

TM-5 818-1/AFM 88-3, Ch. 7 Procedures for Foundation Design of Buildings and Other Structures (except hydraulic structures).

Army Technical Manuals are available from:
U.S. Army AG Publications Center
1655 Woodson Rd.
St. Louis, MO 63114

APPENDIX A

Metric Conversion Factors[1]

0.5 inch = 1.25 cm

1 inch = 2.54 cm

2 inches = 5 cm

3 inches = 8 cm

4 inches = 10 cm

6 inches = 15 cm

10 inches = 25 cm

12 inches = 30 cm

14 inches = 36 cm

15 inches = 38 cm

16 inches = 40 cm

18 inches = 46 cm

20 inches = 50 cm

25 inches = 64 cm

6 feet = 1.8 m

15 feet = 4.5 m

20 feet = 6 m

30 feet = 9 m

50 feet = 15 m

60 feet = 18 m

200 feet = 60 m

800 feet = 242 m

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[1]Conversions are approximate.

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